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Bulletin 97

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

SAMPLING AND ANALYZING FLUE GASES

BY

HENRY KREISINGER

AND

F. K. OVITZ

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SAMPLING AND ANALYZING FLUE GASES.

By Henry Kreisinger and F. K. Ovitz.

INTRODUCTION.

Some of the investigations conducted by the Bureau of Mines have for their object the collecting and disseminating of information regarding methods by which the fuels of the country may be most efficiently used. As the analysis of flue gases tends to develop better methods of firing, which in turn reduces waste of fuel, the Bureau of Mines in this bulletin presents for the benefit of those in charge of boiler plants and all other persons interested detailed information on methods of sampling and analyzing flue gases, and on the utilization of the analyses in promoting boiler-room economy.

This bulletin is intended to be a companion to Technical Paper 80,[a] and is written in plain and nontechnical language, as far as possible, so that it may be readily understood by persons who have not had the advantage of a technical education. Whenever possible, illustrations of apparatus and methods of handling have been used rather than elaborate descriptions.

The material presented in this report is arranged in two parts. The first part contains the description of the apparatus and the methods used in sampling and analyzing flue gases. The second part gives experimental results obtained with the different methods of sampling and collecting flue gas that are recommended in the first part of the report.

Only simple apparatus and methods are considered, as they are accurate enough to show the large heat losses due to the use of too much air, and are also accurate enough to indicate any incomplete combustion losses of economic importance. Without doubt the loss due to large excess of air is the greatest one in the boiler room, and can usually be greatly reduced by making proper use of gas analysis. Before engineers in the isolated industrial plants can be induced to analyze for small traces of combustible gases, they must be first taught how to analyze for carbon dioxide (CO_2), and they must learn to appreciate the great possibilities of reducing loss from large excess of air. Furthermore, in the face of the great difficulty of obtaining a fair

[a] Kreisinger, Henry, Hand firing soft coal under power-plant boilers: Tech. Paper 80, Bureau of Mines, 1915 83 pp.

average sample, discussed in the second part of this bulletin, it is doubtful whether more delicate apparatus for analysis and more refined methods would be of much advantage. Those who wish to obtain information on the more accurate methods of analysis of gases are referred to Bureau of Mines Bulletin 12[a] and Technical Paper 31.[b]

GENERAL STATEMENT.

The determination of the composition of flue gases involves two distinct operations—the sampling of the gases, and the analysis of the sample. Of the two operations the sampling is more important than the analysis, for if the sampling is not done properly the analysis itself is of no value. Also, sampling is usually more laborious than analysis. Great care is necessary, just as it is necessary in sampling coal. In sampling either flue gas or coal a carelessly taken sample is worthless for determining the quality of the gas or coal. Therefore, the device and the methods used in sampling should be well planned and the sampling itself carefully executed.

THE SAMPLING OF FLUE GASES.

In sampling flue gases a small quantity is taken from the stream of gases at any desirable place within a boiler setting. The sample may be taken from the furnace, from among the boiler tubes, or from the breeching, according to the object of the sampling and analysis. The volume of the sample may range from one-half of a cubic foot to a few cubic inches.

In sampling the flue gases the most important feature is that the sample shall closely represent the composition of the stream of gases at the place of sampling, and the device used in sampling must be designed with this object in view. A simple design of such a device for sampling gases in the uptake of a boiler is shown in figure 1.

It consists mainly of a special piece of piping, called the sampler, inserted in the uptake, two collecting bottles, and a steam ejector. These parts are connected by a small-size standard iron piping or ¼-inch copper tubing, as shown in the figure. The operation of the device is indicated by the arrow heads. The steam ejector causes a continuous flow of gas from the uptake through the piping. A small amount of this gas is drawn into the upper collecting bottle and is the sample to be analyzed. The remainder of the gas is rejected with the steam from the ejector through the discharge pipe.

The ejector and the collecting bottles may be placed in any convenient place. In most plants the engine room is the best location;

[a] Frazer, J. C. W., and Hoffman, E. J., Apparatus and methods for the sampling and analysis of furnace gases: Bull. 12, Bureau of Mines, 1911, 22 pp.

[b] Burrell, G. A., and Seibert, F. M., Apparatus for the exact analysis of flue gas: Tech. Paper 31, Bureau of Mines, 1913, 12 pp.

usually they can be placed along the wall separating the engine room from the boiler room. Such location requires a short pipe connection which is always advantageous and easily supervised by the engineer.

Figure 2 shows the location of the ejector, the collecting bottles, and the pipe connections in a typical steam plant. Each boiler is equipped with a separate sampling device independent of the other boilers. One ejector will serve several sampling devices.

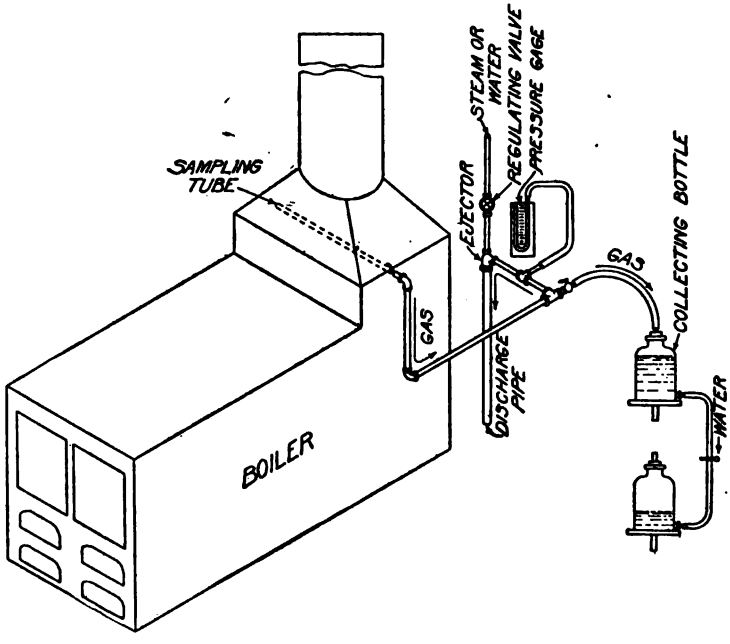


FIGURE 1.—General arrangement of the parts of a flue-gas sampling device.

TYPES OF SAMPLERS.

That part of the sampling device that is inserted into the uptake or into any other place from which it is desired to take a gas sample is called the sampling tube or the sampler. The construction and the location of the sampler are of considerable importance in obtaining a representative gas sample.

SIMPLE OPEN-END SAMPLER.

The simplest and the most commonly used sampler is a plain standard ¼-inch iron pipe placed with the open end in the center of the uptake as shown in figure 3. The gas is taken only from the center of the stream flowing through the uptake, and the sample collected represents only that part of the stream.

The parts of the stream farther away from the center may be and usually are of somewhat different composition than the central part. This difference may amount in some cases to 2 per cent in the CO_2 content; that is, in the central part the gases may contain 8 per cent of CO_2, in another part farther away from the center 10 per cent, and in some other part only 6 per cent. If the setting is very leaky the variation may be greater. In water-tube boilers if the setting is fairly tight the composition of the central part will be within about 0.5 per cent of the average composition of the whole stream. In fire-tube boilers the difference may be as much as 2 per cent. These variations are discussed in the section on "Experimental Results of Sampling and Collecting Flue Gases."

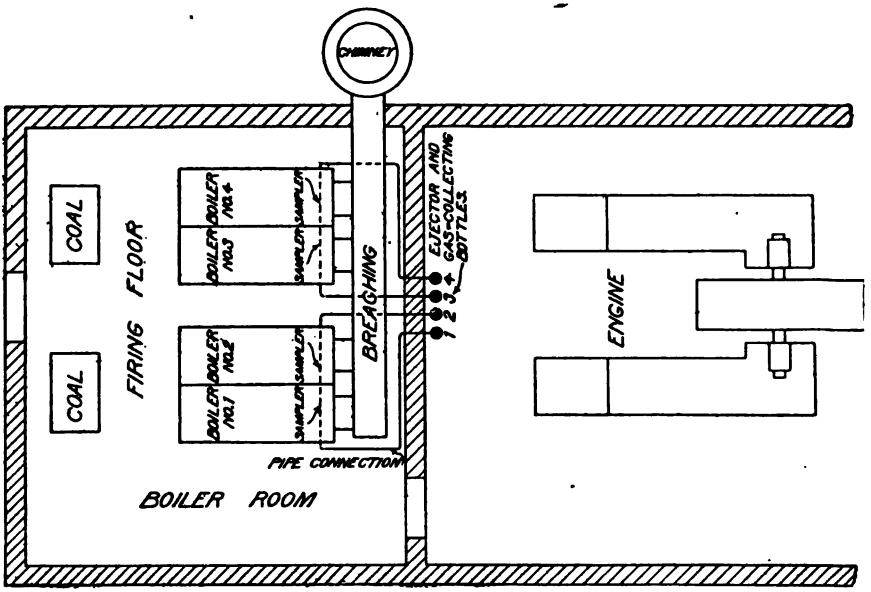


FIGURE 2.—Position of gas-sampling devices and their connections in a typical steam plant. Each of the four boilers is equipped with a separate sampling device.

The open-end single-tube sampler shown in figure 3 has the merit of simplicity. It is easily put in place and can be cleaned readily in case it becomes clogged with soot or ashes. When this sampler is installed the only precaution to be taken is that the open end be placed in the center of the uptake at least 3 feet below the damper and not any nearer than 1 foot to the steam drum. Figure 3 shows a good position for such sampler in a water-tube boiler installation. The sampler is inserted into the uptake through a hole drilled in the brick wall. Leakage around the sampler into the uptake can be stopped with asbestos packing. Figure 4 shows a good placing of the single-tube sampler in a horizontal tubular boiler.

The sampler is placed in the smoke box about 1 foot above the top row of tubes. If a sample is to be taken from any other place within the boiler setting, it is preferable that the open end of the sampler be placed in the center of the stream of gases.

PERFORATED-TUBE SAMPLER.

When it is desirable to obtain a sample that more nearly represents the composition of the entire stream of gases, a sampler of the type shown in figure 5 can be used.

This sampler consists of standard 1-inch iron pipe long enough to reach across the uptake or smoke box. The pipe is closed at both ends. The gas enters into this pipe through a number of $\frac{1}{16}$-inch holes drilled in opposite sides of the pipe about 6 inches apart, as shown in the figure. Through the bushing closing one end of the pipe is inserted $\frac{1}{4}$-inch iron pipe, which extends to the middle of the 1-inch pipe. This inside pipe is connected to the ejector and draws the gas out of the sampler. Such a sampler takes the gas the full width of the uptake at nearly uniform rate, and therefore the sample collected with it more nearly represents the entire stream of gas. Its drawback is that occasionally the small holes become stopped with soot and fine ashes. On this account the sampler must be taken out every few weeks and cleaned. Ordinarily if the gas analysis is used only as an aid to running the fires, it is doubtful whether the extra trouble of making this sampler and keeping it clean pays for the greater accuracy. If, however, the gas analysis is used for computing chimney losses the perforated sampler should be used, especially with fire-tube boilers.

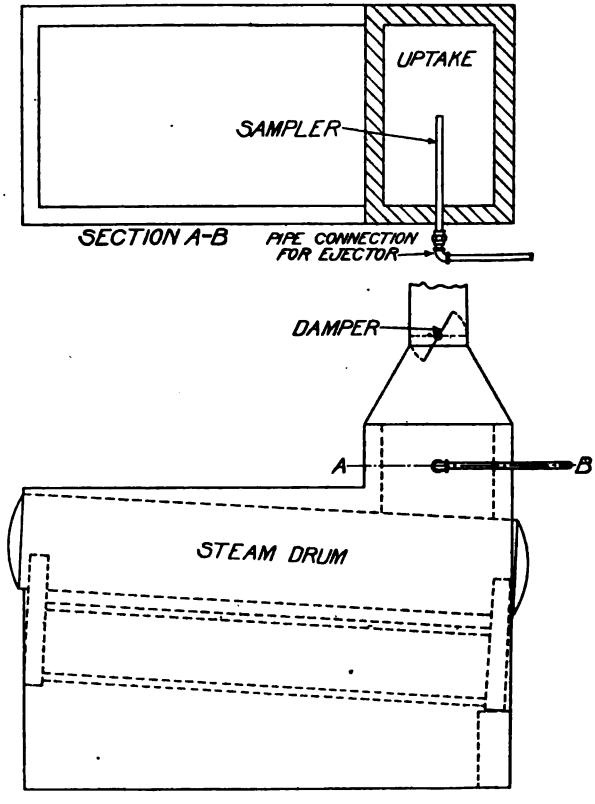


FIGURE 3.—Simple open-end sampler placed in the uptake of a water-tube boiler.

PIPE CONNECTIONS FOR SAMPLER.

The pipe connection is easiest made of standard ¼-inch iron pipe and cast-iron fittings. If possible the pipe should be so laid that there is a gradual drop toward the ejector. There should be no "pockets" in the pipe line, as these would fill up with condensed water vapor, which is always contained in the flue gases. If it is necessary

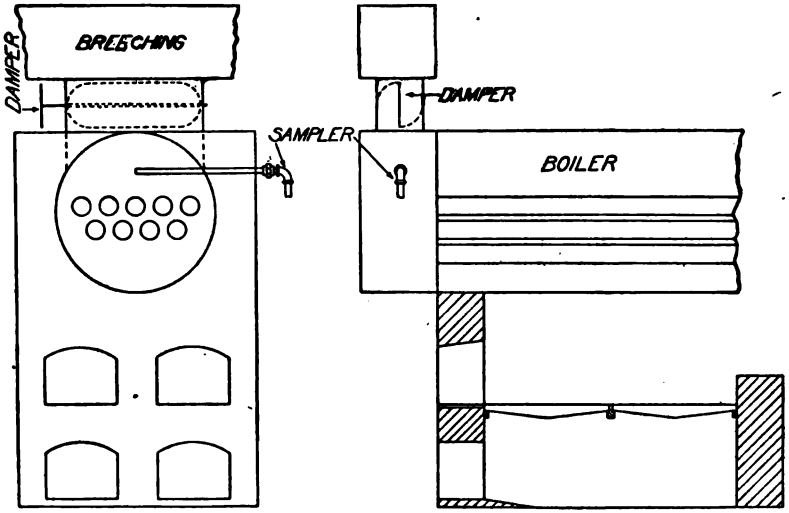


FIGURE 4.—Simple open-end sampler placed in the uptake of a horizontal return-tubular boiler.

to lower the pipe line at any place it is advisable that each low place be provided with a drain cock and a water trap, as shown in figure 6.

During the collection of a sample the drain cock is kept open, and the condensed moisture drains into the bottle. When the bottle is nearly filled, the drain cock can be closed and the bottle emptied. The connections on the water trap should be carefully put together, so that no air can leak into the pipe line. A rubber stopper should

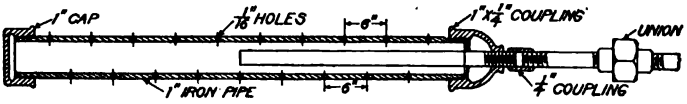


FIGURE 5.—Perforated-tube sampler.

be used in the flask in which the water collects; cork stoppers can not be kept air-tight.

The kind of fittings used at the ejector end of the pipe connection and the arrangement of these fittings are shown in figure 7.

The cocks best suited for the purpose are ¼-inch brass cocks, with male connection, corrugated hose end, and lever handle. Such cocks can be purchased from any dealer in gas fittings for about 20 to 25 cents apiece. The corrugated hose end makes good connection with

a ¼-inch rubber tubing. It is important that the cock delivering gas to the collecting bottles should be connected directly to the gas line as shown in figure 7; that is, no piping should be placed between the cock and the T in the gas line. Such piping would form a pocket of stagnant gas or air which would be drawn into the collecting bottle when the collection of a sample was started. All the joints should be well put together with graphite compound and painted with some thick paint to reduce as much as possible the chances of leakage. Rubber connections should not be painted.

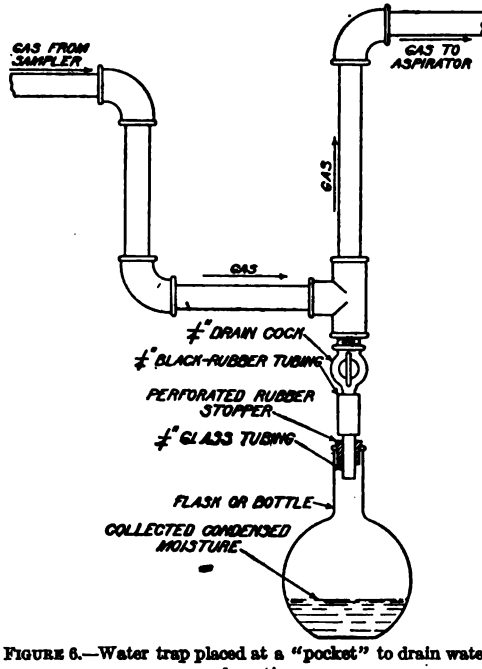


FIGURE 6.—Water trap placed at a "pocket" to drain water condensation.

EJECTOR.

The ejector works on the same principle as the ordinary steam injector used for feeding boilers. An efficient ejector can be made of ¼-inch fitting, as shown in figure 7. The only part that must be made specially is the nozzle. The nozzle consists of a ¼-inch nipple about 1½ inches long, made out of a solid piece of ½-inch round brass, with $\frac{1}{16}$-inch hole. The threading of the ends of the nipple and the drilling of the $\frac{1}{16}$-inch hole had better be done in the lathe, so as to have the hole in the center and the threading true with the hole. It is advisable not to drill the hole any larger than one-sixteenth inch,

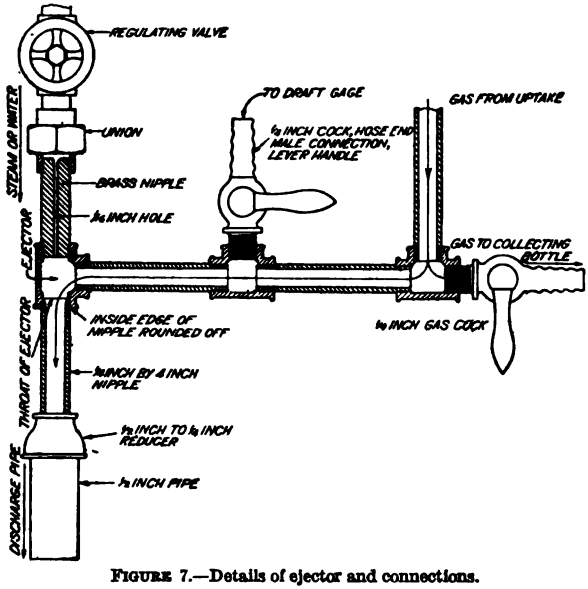


FIGURE 7.—Details of ejector and connections.

because too much steam would be used and the discharge pipe would have to be made of a large-size pipe; otherwise the steam will build up back pressure and reduce the vacuum caused by the ejector. The ¼-inch nipple forming the throat of the ejector should have the inside edge well rounded off, as shown in the figure. With this edge rounded off, the ejector operates more steadily and higher vacuum can be obtained.

In putting the ejector together care should be taken that the nozzle is threaded into the T straight, so that the stream of water or steam issuing from the nozzle hits the center of the throat. If the stream hits too far off the center the suction effect of the ejector might be thereby greatly reduced. With a well-made ejector, using steam, a suction sufficient to lift 3 or 4 feet of water column can be obtained. The suction can be adjusted to any lower value by a steam-regulating valve. A suction of 3 or 4 inches of water is usually sufficient. If water under about 50 pounds' pressure is used in the ejector, a suction of about 5 inches of water can be obtained. When water is used, the ¼-inch pipe forming the throat of the injector should be at least 12 inches long. If steam is used, the discharge pipe beyond the throat should be short and with as few elbows in it as possible. A union placed between the nozzle of the ejector and the regulating valve facilitates cleaning of the nozzle.

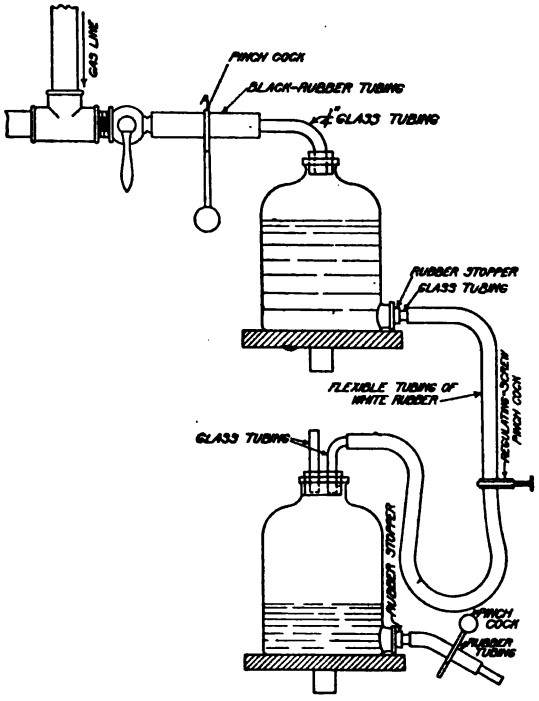


FIGURE 8.—Collecting bottles, showing their connections and arrangement when collecting gas.

COLLECTING BOTTLES AND THEIR CONNECTIONS.

The collecting bottles and their connections are shown in figure 8. Their trade name is "aspirator bottles." They have a side opening near the bottom. For collecting samples over a period of half a day bottles of 2 gallons capacity each are advisable. They can be purchased from any chemical supply or scientific-apparatus supply company at a price of about $1.50 to $2 each.

Both openings of each bottle are provided with well-fitting rubber stoppers, which should be ordered with the bottle. The stopper in the mouth of the bottle has two $\frac{1}{4}$-inch perforations; the stopper in the side opening has only one $\frac{1}{4}$-inch perforation. Cork stoppers should not be used, because they can not be kept gas-tight.

GLASS TUBING.

The glass tubing used in making the connections is $\frac{9}{32}$-inch outside and about $\frac{3}{16}$-inch inside diameter. About 20 feet of the tubing weighs 1 pound. Soft glass is better suited for this purpose, because the tube can be easily bent to any shape by heating to a dull-red temperature in a gasoline torch. While the tubing is being heated, it should be slowly revolved in the flame, so that it is heated uniformly around the circumference. If a bend at right angles is to be made, about 2 inches of the tube should be heated to a uniform dull-red heat and then removed from the flame before attempt is made to bend it. A wide flame is preferable to a pointed one for heating glass tubing that is to be bent. If the flame can not be made wide enough, the tubing should be moved back and forth sideways, so as to get sufficient length of the tubing heated. If only a short piece of the tubing is heated, a very sharp bend will be formed and the tubing will flatten down and nearly close the hole.

The tubing can be broken off at any desired place by filing a deep scratch on the glass and then exerting a slight pressure with the thumbs on the side opposite the scratch.

The glass tubing can be purchased from any chemical supply company at about 40 or 50 cents a pound. It comes in lengths of about 30 to 36 inches.

RUBBER TUBING.

The rubber connection between the upper bottle and the gas line should be made of $\frac{1}{4}$-inch black seamless unvulcanized rubber tubing of heavy walls. Such tubing can be purchased from any chemical supply company for about 15 cents a foot. The black rubber remains elastic and maintains gas-tight joints, and should be used wherever a gas-tight joint is required.

The connection between the two bottles can be of $\frac{1}{4}$-inch white-rubber tubing, light wall, cloth impression. Such tubing can be purchased for about 8 or 9 cents a foot. It is not so elastic as the black-rubber tubing and therefore it is not recommended for gas connections that must remain tight. However, for the water connection between the two bottles it is cheaper and even more durable than the black tubing.

TUBING CLAMPS.

Three clamps are needed for each set of collecting bottles. Of these the one used on the water connection between the two bottles should be a screw clamp (fig. 9). This type of clamp permits an easy adjustment of the quantity of water flowing from the upper bottle into the lower one. The other two clamps should preferably be of the spring type commonly called "pinch cocks" (fig. 9). This type can be used to better advantage where it is desired to have the rubber connection fully open or completely closed.

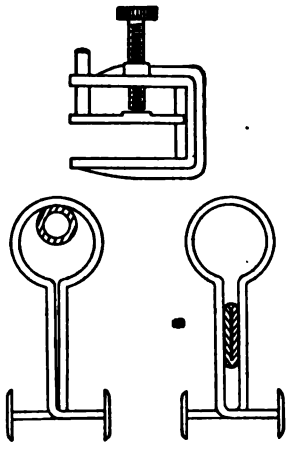


FIGURE 9.—Tubing clamps for closing rubber tubing. Top view shows a screw clamp to be used when fine adjustment of the flow through the tube is desired. Bottom views show a pinch cock for completely closing the rubber tubing.

The cost of the large screw clamp is about 15 cents; the price of the spring pinch cocks is about 6 cents each. They can be bought from any chemical supply company. The screw pinch cock should have the end of the screw covered with metal, so that the screw will not cut the rubber tubing.

PROCEDURE IN COLLECTION OF GAS SAMPLES.

DETAILS OF ARRANGING APPARATUS.

Figure 8 shows the arrangement of the bottles with connections made for collecting a gas sample. The upper bottle is connected to the corrugated hose end of the lever cock. This connection should be as short as possible. The lower bottle is placed 2 to 4 feet below the upper one. The greater this difference between their elevations, the more uniform is the rate of collecting the gases over long periods. The rubber-tube connection enters the lower bottle through the mouth and not through the side opening.

At the start the lower bottle is nearly empty. The upper one is completely filled with water; in fact, it is advisable to run the water into the rubber tubing as high as the pinch cock, so that all the gas or air will be expelled from the bottle. Care should be taken that the short piece of glass tubing does not protrude below the rubber stopper. If it should, a pocket of gas will be formed below the stopper and it will be impossible to expel this gas. All the pinch cocks as well as the lever cock on the gas line are shut. The ejector should run several minutes with a suction of 3 or 4 inches of water before the collection of the gas sample is begun. The suction is measured by the draft gage attached as shown.

To start collecting the gases the lever cock on the gas line and the pinch cock *A* are fully opened. The regulating screw pinch cock is

then partly opened and adjusted to any desired flow of water from the upper bottle into the lower one. The correct adjustment of the regulating cock can be made much easier by observation of the quantity of water dripping into the lower bottle than by observing the dropping of the water level in the upper bottle. When the water drips at the rate of three drops in 2 seconds, it takes about 6 hours to empty the upper bottle. As the water flows out of the upper bottle gas is drawn in from the gas line and takes the place of the water. The air in the lower bottle escapes through the short piece of glass tubing in the rubber stopper.

METHOD OF OBTAINING EFFECTIVE HEAD OF WATER.

The effective head causing the water to flow through the rubber connection between the two bottles is the difference between the elevation of the water level in the upper bottle and the elevation of the mouth of the lower bottle. This effective head is changed only by the drop of the water level in the upper bottle and not by the rise of the water level in the lower one. This relation holds only when the bottles are connected as shown in figure 8.

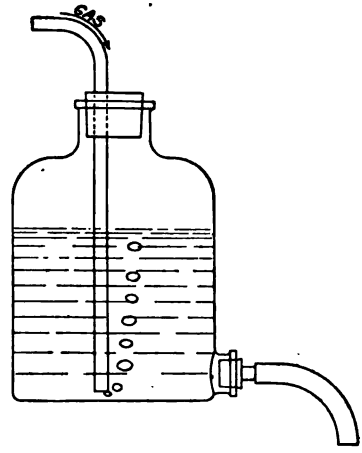


FIGURE 10.—Connections of the upper collecting bottle to maintain constant effective head. The gas bubbles through the water. This arrangement is not recommended.

If the connections were made to the side outlet of the lower bottle, the rise of the water level in it would also diminish the effective head. Variation in the effective head causes a corresponding variation in the rate of flow of water from the upper bottle into the lower one. Consequently the rate of collecting the gas sample is reduced as the effective head becomes smaller, although the adjustment of the regulating pinch cock remains the same. Therefore the variation in the effective head should be as small as possible. The greater the difference in the elevation of the two bottles the smaller will be the reduction in the rate of collecting the gas sample due to the drop of water level in the upper bottle. A difference of more than 2 feet gives fair results.

A constant effective head can be obtained by extending the glass tube so as to bring the gas nearly to the bottom of the upper bottle, and so as to let the gas bubble through the water, as shown in figure 10.

With this arrangement the effective water head is equal to the difference of elevation between the lower end of the glass tube and the mouth of the lower bottle and is of course constant. However, this

arrangement is not recommended, because as the gas bubbles through the water a considerable amount of the carbon dioxide (CO_2) may be absorbed by the water or given off, and an error amounting to several per cent may be introduced in the CO_2 determination. The seriousness of this error is shown by experimental results given in Table 9 on page 6 .

EFFECT OF ABSORPTION OF CARBON DIOXIDE IN WATER.

Carbon dioxide is much more soluble in water than oxygen and nitrogen. The respective solubility of these gases is approximately 90, 2, and 1. Furthermore, water from a well or river is usually more nearly saturated with oxygen and nitrogen than with carbon dioxide. When the upper collecting bottle is freshly filled with water and flue gas is bubbled through the water, as shown in figure 10, a large part of the carbon dioxide is absorbed by the water. Thus if the flue gas contains 12 per cent of CO_2 when it enters the bottle, 6 per cent of the 12 may be absorbed by the water, so that the analysis of the collected sample may show only 6 per cent of CO_2. If several consecutive samples containing 12 per cent of CO_2 are collected, the water becomes saturated and the absorption of CO_2 is gradually reduced. Finally, the analysis of the last sample may show nearly 12 per cent. If, however, after the water has been saturated with flue gas containing 12 per cent of CO_2, a sample having only 6 per cent of CO_2 is collected, the water gives off some of the CO_2 absorbed from previous samples, and the analysis of the sample may show 9 per cent of CO_2.

That the error caused by the absorption of CO_2 by water is a serious one is shown by the experimental results given on pages 59 to 64. Even when the gas is collected over water, as shown in figure 8, some carbon dioxide may be absorbed or given off, although to a smaller degree. The absorption is larger if the gas sample is allowed to stand in the bottle a long time. Therefore, to reduce this error, the sample of gas should be analyzed immediately after the collection has been completed. The error due to this cause can be further reduced if salt brine be used instead of water. Carbon dioxide is less soluble in brine than in water. The absorption of CO_2 could be completely avoided if the bottles were filled with mercury instead of brine or water. However, the cost of mercury and the increased difficulty in handling the apparatus make the use of mercury inadvisable for the ordinary boiler-room or engine-room work.

DISPOSAL OF SURPLUS OF SAMPLE.

After a sample has been collected and a part of it taken for analysis, the remainder of the gas can be discharged into the gas line by raising the lower bottle and changing the connection to its side outlet, as

shown in figure 11. All the cocks, including the lever cock on the gas line, are fully opened.

The water flows back into the bottle connected to the gas line and forces the gas out through the discharge line. When the water has risen to the pinch cock *A*, all the cocks are closed and the bottles changed to the position shown in figure 8. The bottles are then ready for collecting another sample.

COLLECTION OF "GRAB" SAMPLE WITH ORSAT APPARATUS.

Sometimes it is desired to collect a sample of gas from various places within the setting over a short period of a few seconds. This can be done most easily by drawing the gas sample directly into the measuring burette of an Orsat apparatus, using an open-end tube sampler. Figure 12 shows a method of taking a "grab" sample from the third pass of a cross-flow water-tube boiler, the sampling tube being inserted through the cleaning holes.

Each time a sample for analysis is taken, the air should be removed from the sampler and the connections by drawing the air into the measuring burette and discharging it through the three-way cock.

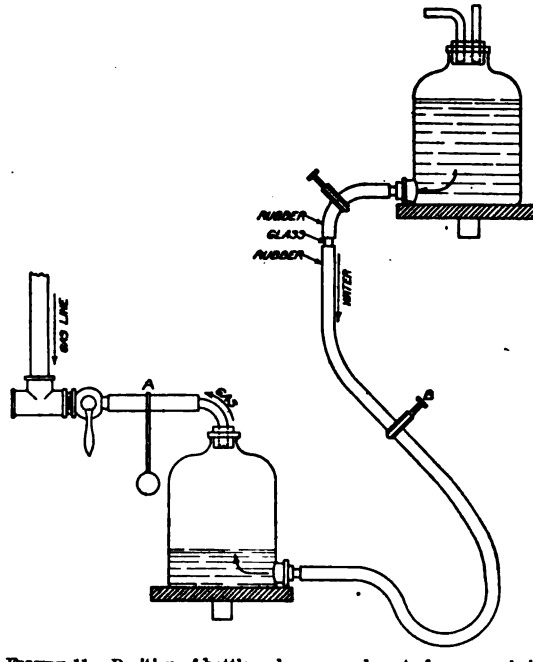


FIGURE 11.—Position of bottles when unused part of gas sample is being discharged and the bottle used for collecting sample is being filled with water. *A*, spring pinch cock; *B*, screw pinch cock.

The sampler should be made of small-size tubing, and the rubber connection should be as short as practicable in order that the volume of air they hold may be small and quickly drawn out. Ordinarily, filling the measuring burette two or three times suffices to remove the air. If only CO_2 is to be determined, $\frac{3}{16}$ inch or $\frac{1}{4}$ inch copper tubing is convenient for use as a sampler. One-quarter inch copper tubing holds approximately 1 cubic inch of gas for every 3 feet of its length, so that the measuring burette of a half-size Orsat apparatus at one filling empties about 9 feet of the tube. The capacity of $\frac{1}{4}$-inch standard iron pipe is about 1 cubic inch of gas for every 10 inches of its length, so that one filling of the measuring burette of a half-size

apparatus empties only about 30 inches of the pipe. These figures show the advantage of using small-size tubing as a sampler when the gas is collected directly in the Orsat apparatus.

The perforated-pipe sampler shown in figure 5 is not well adapted for this method of sampling because of its large gas-holding capacity. The manipulation of the Orsat apparatus when the sample is being drawn is described in the next chapter.

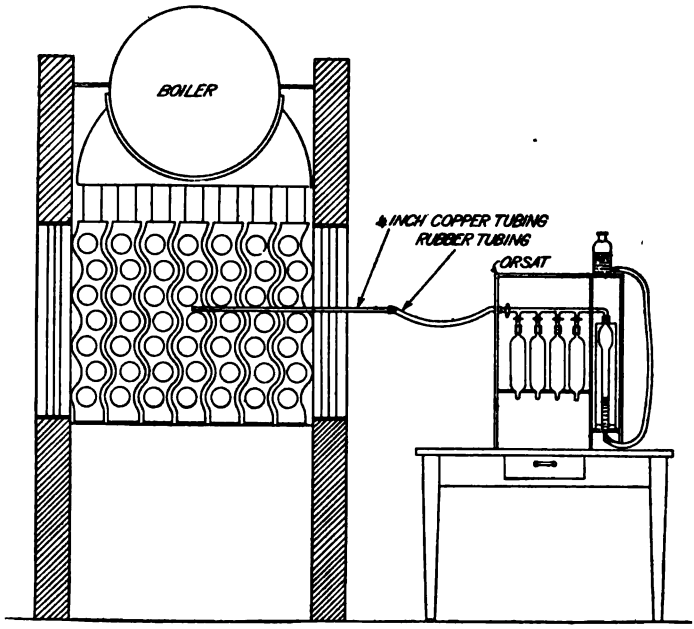


FIGURE 12.—Arrangement of apparatus for collecting "grab" sample from the third pass of a vertically baffled water-tube boiler.

ANALYSIS OF FLUE GASES.

Flue gas consists of carbon dioxide, oxygen, carbon monoxide, and nitrogen; but sometimes may contain small proportions of hydrogen and methane. Water vapor and a little sulphur dioxide are always present, but as regards boiler-room economy these constituents have little significance. Usually only the carbon dioxide, oxygen, and carbon monoxide are determined and the remainder is considered nitrogen. Frequently the carbon dioxide is the only constituent determined, this alone giving sufficient information as to the economic performance of the furnace.

The flue gases are usually analyzed with a portable apparatus commonly known as the Orsat, shown in figures 13 and 14. An analysis consists of successively absorbing the different constituents of the gas sample and of measuring the volume of the sample before and after each absorption.

DESCRIPTION OF ORSAT APPARATUS.

The essential parts of the Orsat apparatus are a measuring burette, three absorption pipettes, a leveling bottle, and a header, all of which are made of glass. These glass parts are inclosed in a compact wooden case.

MEASURING BURETTE.

The measuring burette is a cylindrical glass vessel graduated into 100 units, each unit being graduated into fifths. The measuring burette of a full-size Orsat apparatus has a volume of 100 c.c.; the volume of the burette of the half-size apparatus is 50 c. c. A volume of 16.38 c. c. is equal to 1 cubic inch. The burette is used for measuring the volume of gases during the process of analysis. It is inclosed in a water jacket which prevents sudden changes in temperature while the analysis is being made.

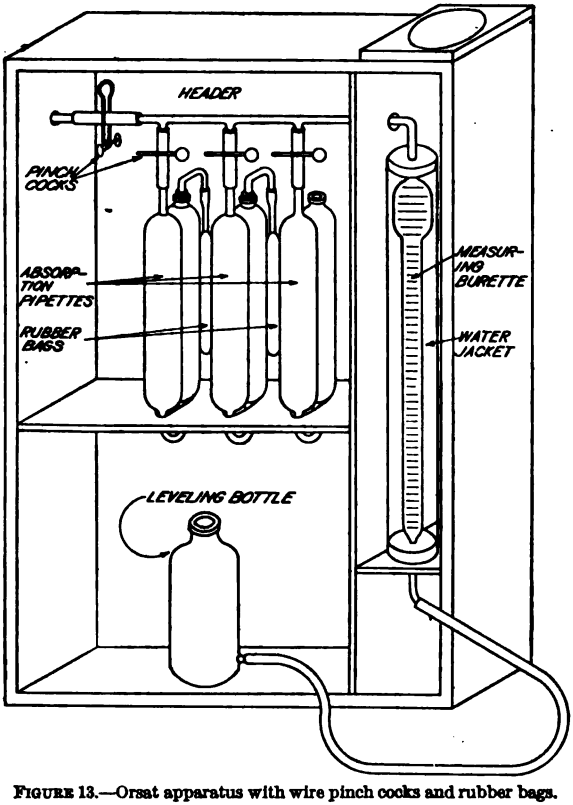


FIGURE 13.—Orsat apparatus with wire pinch cocks and rubber bags.

ABSORPTION PIPETTES.

The absorption pipettes are U-shaped glass vessels and contain solutions for absorbing the three principal constituents of the flue gas. The one nearest to the measuring burette contains potassium hyrdoxide solution for absorbing carbon dioxide; the second one contains an alkaline solution of pyrogallic acid for absorbing oxygen; and the third contains ammoniacal solution of cuprous chloride for absorbing carbon monoxide.

Two kinds of absorption pipettes are shown in figure 15.

The pipette with the opening and the ground-glass stopper near the top is not as good a design for general boiler-room work as the plain one. The stopper may become loose and the gas or solutions may leak out and cause trouble. One arm of the pipette contains

glass tubes to increase the surface of the liquid when in contact with the gas. To the other arm is attached a water seal or rubber bag to protect the solutions from deterioration by contact with air. The method of attaching the water seal or rubber bags is shown in figure 16.

The water seal requires an extra pipette, three No. 0 rubber stoppers with one hole, a glass T, and two right-angled glass bends. The joints should be made with ¼-inch black-rubber tubing. The rubber bags are attached by means of a rubber stopper and short piece of glass tubing. They should be air tight, as otherwise they may cause a great deal of trouble. After two or three months the rubber becomes hard and porous and the bags should be replaced by new ones. The water seal is more difficult to attach, but once attached to the apparatus it is permanent and gives no trouble. Only the solutions for absorbing oxygen and carbon monoxide need to be protected.

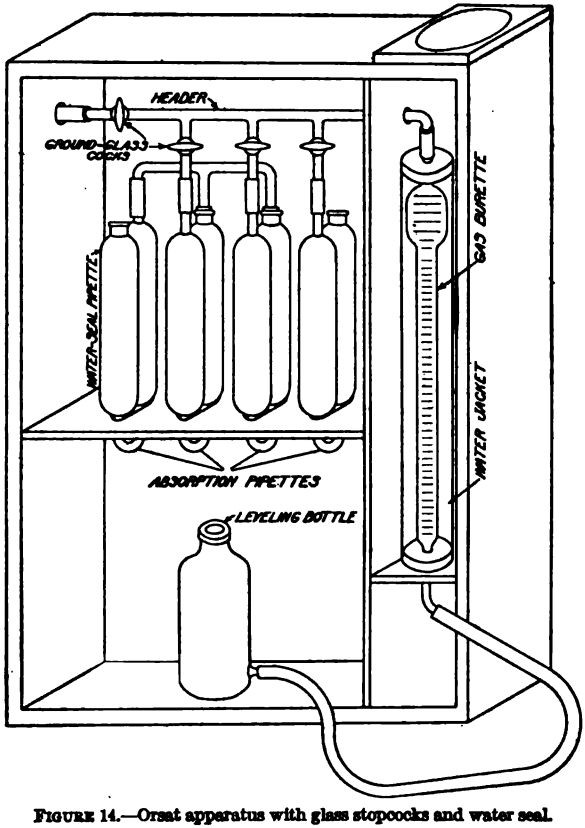


FIGURE 14.—Orsat apparatus with glass stopcocks and water seal.

LEVELING BOTTLE.

The leveling bottle, which is connected to the measuring burette with about 3 feet of black-rubber tubing, contains water. Lowering or raising the leveling bottle causes the water to act as a piston and draw gas into the measuring burette or force gas out of it into any absorption pipette. The water in the leveling bottle also is used to regulate the pressure on the gas when its volume is being measured.

HEADER.

The header is made of glass tubing of small bore. The measuring burette and absorption pipettes are attached to it with ¼-inch black-rubber tubing. All the joints must be gas tight. There is a glass stopcock on the header between each pipette and the burette, and at one end there is a three-way stopcock through which gas is taken into or discharged from the apparatus. The three-way cock has a spot of colored glass on it to indicate the direction of flow. Spring pinch cocks can replace the three stopcocks between the pipettes and the burette and thereby somewhat reduce the cost of the apparatus. The writers find the glass cocks more convenient to manipulate, but the glass cocks require greater care to keep them in good working condition. They must be kept lubricated with vaseline so that they will turn easily and will not stick. The vaseline should be applied in a thin film on the bearing surface of the valve and all excess avoided, for if too much is applied the small holes in the valves may become stopped.

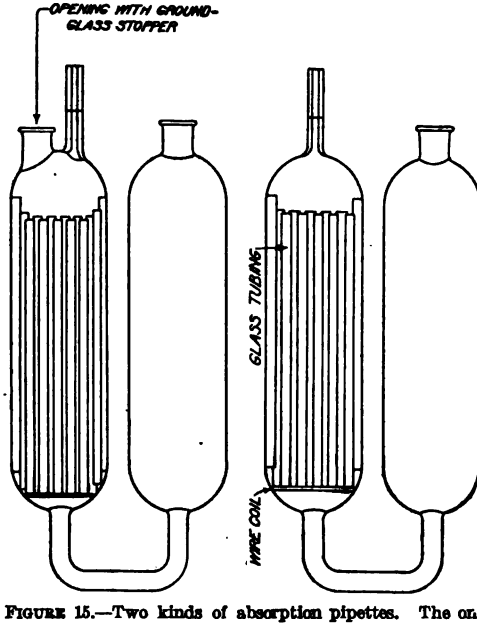


FIGURE 15.—Two kinds of absorption pipettes. The one without ground-glass stopper is the better design.

COST OF APPARATUS.

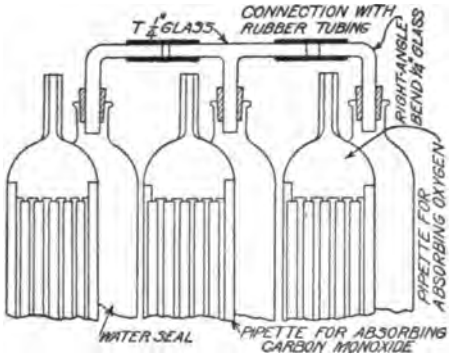
The half-size Orsat is lighter than the full size and therefore is preferable if the apparatus is to be carried from place to place. The apparatus can be purchased from any chemical-supply company. The cost of the full-size type with glass stopcocks is about $20, or with spring pinch cocks about $18. The half-size type correspondingly equipped costs about $18 and $16. Usually the apparatus is fitted with rubber bags to protect the solutions; if the water seal is wanted it must be specified when purchasing.

MANIPULATION OF ORSAT APPARATUS.

In a gas analysis the manipulation of the Orsat apparatus consists mainly of two operations—moving the gases into the different parts of the Orsat apparatus and measuring their volume.

MOVING THE GASES.

The moving of the gases is done with the water in the measuring burette and the leveling bottle. The water acts as a piston; when the leveling bottle is raised the water flows by gravity into the measuring burette and forces the gases into one of the absorption pipettes or out of the apparatus, depending on which valve is open. If the leveling bottle is lowered, the water flows by gravity from the burette into the leveling bottle and the gas is drawn from the apparatus into the burette. This manipulation in indicated in figures 17 and 18.



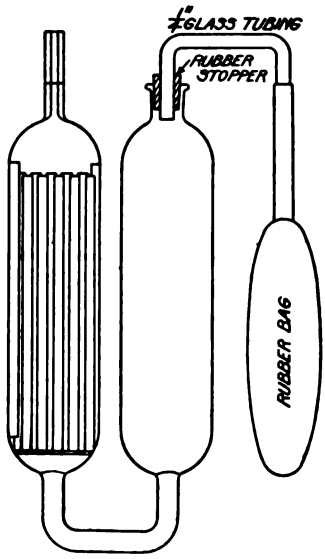


FIGURE 16.—Method of attaching water seal and rubber bags for protection of the solutions from air.

In the illustrations the movement of water and gases is indicated by the arrows. Figure 17 shows the process of drawing the gas sample from the collecting bottle into the Orsat apparatus, the water flowing out of the burette into the leveling bottle. The three-way cock on the Orsat apparatus is opened in such a way that the gases flow from the collecting bottle into the measuring burette; the valves on all the absorption pipettes are closed.

When gas is being drawn from the absorption pipette, care should be taken not to draw the solution into the valve or to run the solution into the water in the measuring burette. The solution rises slowly as long as the level is in the wide part of the pipette, but as soon as it reaches the small bore of the neck it rises rapidly, and before an inexperienced operator realizes what is happening part of his solution is drawn into the measuring burette. The best way to avoid such accidents is to operate the Orsat apparatus as shown in figure 19. The leveling bottle is manipulated with the right hand while the rubber-tube connection is held between the thumb and first finger of the left hand.

If pressure be exerted on the rubber tubing, the flow of gas can be so reduced that it can be stopped easily with the top of the solution at any desired point in the neck of the pipette. When the solution has been brought to the point desired, the analyst may hold it there by pinching the rubber tubing, the leveling bottle being placed on the stand so as to leave the right hand to manipulate the valve. The same manipulation should be used when the gases are being forced into the absorption pipettes.

MEASURING VOLUME OF GASES.

The measurement of the volume is the most important operation in the analysis of gases. During any one analysis all measurements of the gas volume must be made under constant temperature and pressure.

A rise in temperature increases the volume of the gases. It is to avoid the change in the temperature that the measuring burette is water-jacketed. To further decrease the possibility of temperature changes, the Orsat apparatus should be in a place free from draft or heat radiation from the boiler or engine.

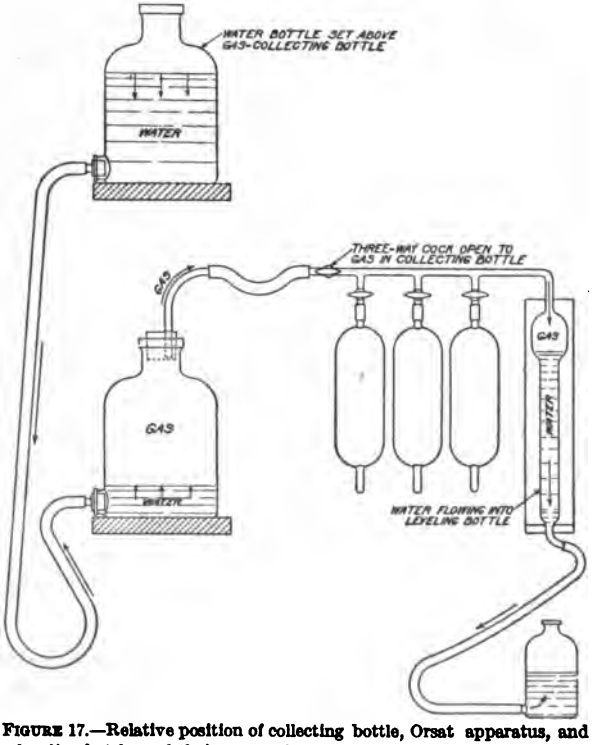


FIGURE 17.—Relative position of collecting bottle, Orsat apparatus, and leveling bottle, and their connections when gas is being drawn into the burette.

A change in pressure changes the volume of gases. Inasmuch as the atmospheric pressure changes little and any change takes place slowly, the volume of gases is conveniently measured under atmospheric pressure. The gas in the measuring burette is brought under atmospheric pressure by holding the leveling bottle at such position that the water level in the measuring burette and that in the leveling bottle are at the same height; that is, so that a horizontal line will pass through both levels. The position of the leveling bottle when the volume of the gases is read is shown in figure 20. When the reading is taken, the rubber tubing must be free from kinks.

The necessity of bringing the two levels to the same height before the volume is read can be appreciated by noting that raising or lowering the leveling bottle will give almost any desired volume in the measuring burette.

Another precaution that should be taken before the volume is read is to allow the water to drain down the sides of the burette for the same length of time. Under ordinary conditions half of a minute is enough. The inside of the measuring burette should be kept clean, in order that the water may drain well.

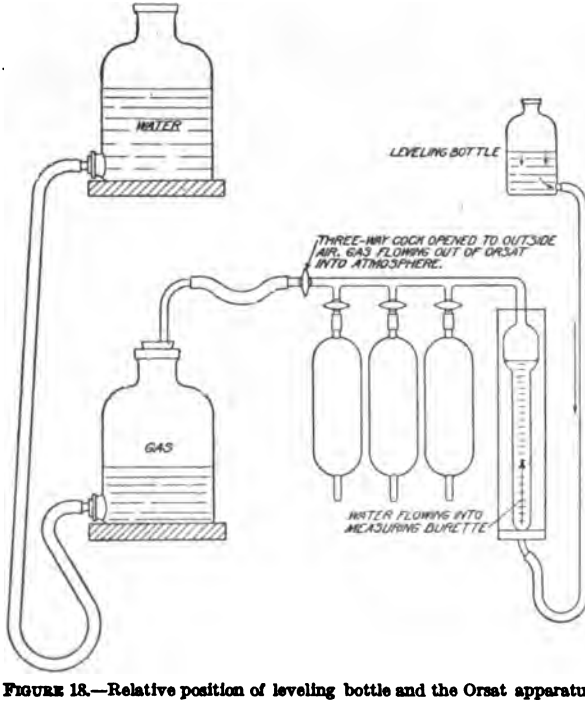


FIGURE 18.—Relative position of leveling bottle and the Orsat apparatus when gas is being expelled from the apparatus. The three-way cock is opened to the atmosphere.

TESTING FOR LEAKS.

Careful attention should be given joints on the Orsat apparatus. In making connections the ends of the glass tubing should be brought close together. The rubber joints must be perfectly tight. To test for leaks the measuring burette is about half filled with air and all the stopcocks are closed. The leveling bottle is then lowered about 2 or 3 feet, the air inside the burette being thus placed under a reduced pressure. If the water in the burette falls to a certain point and then remains stationary, there is no leak. If it continues to fall slowly, there is a leak, which must be stopped before the analysis goes further.

PREPARING ORSAT APPARATUS FOR ANALYSIS.

Before an analysis is begun each solution must be brought to the mark on the stem of the pipette and the corresponding valve in the header closed. Any gas that has been drawn into the measuring burette is expelled and the water is forced into the small-bore neck of the burette. The apparatus is then ready for use in an analysis.

PROCEDURE IN MAKING THE ANALYSIS.

CLEANING THE APPARATUS.

To take gas into the apparatus the end of the header is connected to the gas supply, such as a collecting bottle. The gas is drawn in by lowering the leveling bottle, with the three-way cock opened to the gas supply, as shown in figure 17. It is forced out by raising the leveling bottle with the three-way cock opened to the outside air, as shown in figure 18. Before a part for analysis is retained three or four burettes of gas are drawn into and forced out of the apparatus. The apparatus is thus cleaned of all the residue from the previous analysis, or of air, and a true sample of the flue gas to be analyzed can be obtained.

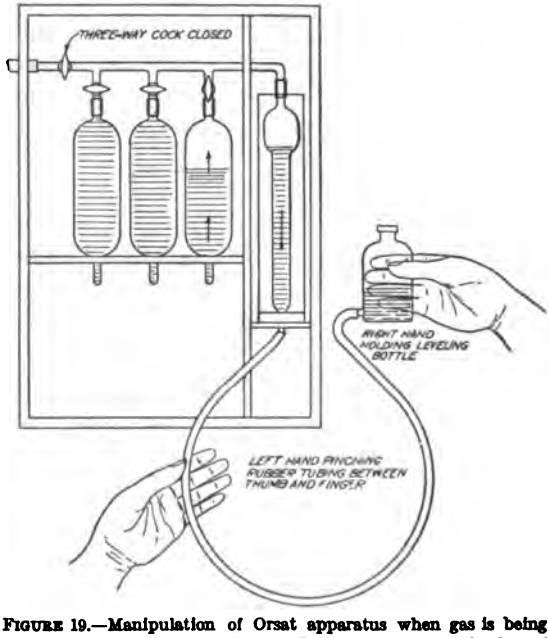


FIGURE 19.—Manipulation of Orsat apparatus when gas is being drawn out of absorption pipette. Left hand throttles the flow of water, thus controlling the flow of gas from the absorption pipette; right hand holds the leveling bottle.

MEASURING THE SAMPLE.

After three or four burettes of gas have been rejected, a burette of gas is drawn into the apparatus and the three-way cock is closed. The gas is placed under a slight pressure by raising the leveling bottle until the water is above the zero mark. The rubber tubing is then pressed between the thumb and first finger of the left hand and the leveling bottle is placed below the lower end of the measuring burette. The pressure exerted with the left hand on the rubber tubing is slowly released and the water allowed to fall to the zero mark. It is held at this point by pinching the rubber tubing, while the three-way cock is opened to the outside air for a few seconds and closed. When the pressure on the rubber tubing is released and the water in the leveling bottle is held at the same level as the water in the burette, the level line should pass through the zero mark. If the line of common level does not pass through zero mark, the manipulation just described must be repeated.

CARBON DIOXIDE DETERMINATION.

When the volume of gas has been adjusted so that the water level passes through zero, the gas is forced into the pipette, containing potassium hydroxide solution. This is done in the manner indicated in figure 19, the leveling bottle being raised above the Orsat apparatus so that the water flows into the burette.

The rubber tubing is pressed between the thumb and first finger of the left hand, the leveling bottle placed on top of the Orsat apparatus, and the valve leading to the first pipette is opened. The pressure of the fingers on the rubber tube is released, allowing the water to run from the leveling bottle into the burette and forcing the gas into the pipette. When the water in the burette reaches the small-bore neck the leveling bottle is lowered and the gas is drawn back into the burette, care being taken not to draw the solution into the valve. The flow of gas can be nicely regulated with the pressure on the rubber tubing as described in connection with figure 19. This operation is repeated three times, the gas being slowly forced into and drawn out of the pipette.

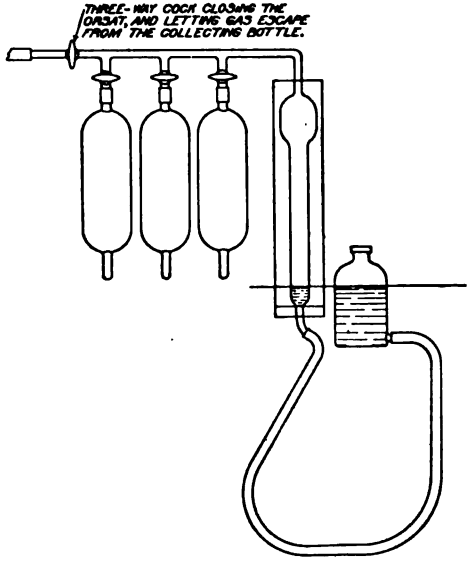


FIGURE 20.—Position of leveling bottle when gas volume is read. Water in measuring burette and leveling bottle at the same level.

After the gas has been drawn out of the pipette the last time the solution is brought to the mark on the neck and the stopcock is closed. The volume is measured by bringing the water in the leveling bottle to the water level in the measuring burette, as shown in figure 20. The gas is then forced again into the pipette and drawn back into the burette and the volume measured once more. If the two readings are the same, all of the carbon dioxide has been absorbed; if not, the operation is repeated until two readings are the same. The reduction in the volume of gas is due to the absorption of the carbon dioxide by the solution and is the measure of the amount of this constituent in the gas. It is well to remember that when the gas is drawn out of the pipette the solution should always be brought to the same mark on the stem and the valve closed before the volume is measured.

The solution can be brought to the mark with a nicety by throttling the water in the rubber tubing with the fingers of the left hand. In fact the transferring of the gas from the burette to the pipettes and back again can be done a great deal easier if the left hand is held constantly on the tubing, ready to throttle the flow of water whenever an exact adjustment of the levels is required. The manipulation is that indicated in figure 19. Care should be taken not to run water into the header, and particularly not to draw solution into the stopcocks.

If the glass tubes in the pipettes are not properly arranged, gas may pass through them into the other arm of the absorption pipette and be lost. The tubes should be watched when the gas is being passed into the pipette, and all gas loss avoided.

OXYGEN DETERMINATION.

After all the carbon dioxide has been taken out, the remaining gas is forced into the second pipette containing an alkaline solution of pyrogallic acid, which absorbs the oxygen. The gas is moved back and forth as in the absorption of carbon dioxide. Oxygen is absorbed much slower than carbon dioxide; therefore the gas must be passed into and out of the pipette a greater number of times. The absorption should be continued until two successive measurements are the same. The contraction in volume is the amount of oxygen in the gas.

CARBON MONOXIDE DETERMINATION.

Carbon monoxide is absorbed in an ammoniacal solution of cuprous chloride. After all the carbon dioxide and oxygen have been removed the carbon monoxide in the remainder of the gas is absorbed in the third pipette in the same manner as in the preceding determinations. Accurate determination of the carbon monoxide is difficult. Cuprous chloride solution, after being used for some time, will not remove all the carbon monoxide. Moreover, if gas containing no carbon monoxide is passed into a solution that has absorbed carbon monoxide previously some of it will be given off, and an increase in volume will result. To obtain accurate results the solution must be renewed frequently.

EXAMPLES OF ANALYSIS.

Analysis is started with the measuring burette filled with gas to the zero point. The gas is forced into and drawn out of the first pipette three times. The volume measures, say, 5.2. The gas is forced into and drawn out of the pipette once more. The volume is the same as before; therefore all the carbon dioxide has been absorbed. The contraction, or the carbon dioxide absorbed, is 5.2. The remaining gas is forced into and drawn out of the second pipette five times. The

volume is found to be, say, 19.4. The gas is forced into and drawn out of the pipette twice more, and the volume is found to be, say, 19.6, showing that all the oxygen had not previously been absorbed. If, after two more passages, the volume remains 19.6, all the oxygen has been removed. The contraction is 19.6 minus 5.2, or 14.4, which is the amount of oxygen in the gas. The remaining gas is forced into and drawn out of the third pipette three times. The volume is measured and no contraction is observed; therefore no carbon monoxide is present.

An analysis is recorded in percentage by volume. As mentioned previously, the measuring burette of an Orsat apparatus is graduated to 100 units, the units being further graduated to fifths. If the sample fills the burette to the zero mark, the contraction can be read in terms of percentage by volume. If the sample of gas does not fill the burette to the zero mark, the contraction divided by the volume of gas taken for analysis and multiplied by 100 equals the percentage by volume. An example will illustrate: The volume of gas taken for analysis is 49.0 units. After carbon dioxide has been absorbed the volume is 44.2 units. The contraction is $49.0-44.2=4.8$ units. $\frac{4.8}{49.0}\times 100=9.8$ per cent of carbon dioxide. After the oxygen has been absorbed the volume is 39.8 units. The contraction is $44.2-39.8=4.4$ units. $\frac{4.4}{49.0}\times 100=9.0$ per cent of oxygen. It is much better, if possible, to fill the measuring burette to zero point.

PRECAUTIONS TO BE TAKEN TO OBTAIN ACCURATE RESULTS.

Accurate results can be obtained only by close attention to details. The apparatus must be perfectly tight. A test for leaks should be made each day before an analysis is begun. The constituents must be absorbed in the proper order—first, carbon dioxide; second, oxygen; and third, carbon monoxide. The solutions for oxygen and carbon monoxide absorb carbon dioxide and the solution for carbon monoxide absorbs oxygen also; therefore, each constituent must be removed completely before absorption of the next is begun. The solutions should be replaced by fresh ones when the absorption becomes slow. All measurements of volume must be made under the same pressure. Changes in temperature during an analysis should be avoided.

PREPARATION OF SOLUTIONS.

The absorbing agents employed are solutions that are prepared by dissolving a weighed quantity of chemicals in a measured volume of water. If no balance and graduate are available with which the materials can be weighed and measured, the quantities can be approxi-

mated in cubic inches with fair accuracy. However, it is advisable to provide an 8-ounce glass graduate, which will be found useful in measuring liquids. It can be bought from any chemical supply house for about 40 cents.

POTASSIUM HYDROXIDE SOLUTION FOR ABSORBING CARBON DIOXIDE.

For the preparation of the solution for absorption of carbon dioxide potassium hydroxide not purified by alcohol should be used. It can be bought in sticks about five-sixteenths of an inch in diameter. A stick 5 inches long weighs approximately one-half ounce. Three hundred and thirty grams of potassium hydroxide, about 14 ounces, or twenty-eight 5-inch sticks, are dissolved in 1,000 cubic centimeters, about 34 fluid ounces or 61 cubic inches, of clear water.

The solution can be made in a bottle or in an open vessel. If a bottle is used, the potassium hydroxide should be added to the water slowly to prevent breaking the bottle by the heat produced. If an open vessel is used, the water can be poured into the potassium hydroxide at once. The solution should be cooled before it is transferred to the bottle. If a precipitate forms, as is usually the case, it should be allowed to settle and the clear liquid poured off without disturbing the sediment.

Potassium hydroxide, thus prepared, can be kept in a rubber-stoppered bottle and used as a stock solution for carbon dioxide determinations and for making alkaline pyrogallic acid solution. A pipette full can be used for about 150 determinations of carbon dioxide.

ALKALINE PYROGALLIC ACID SOLUTION FOR ABSORBING OXYGEN.

The alkaline pyrogallic solution for absorbing oxygen is prepared by dissolving in the graduate or other glass vessel 10 grams (about one-third of an ounce or 2½ cubic inches) of pyrogallic acid in 25 cubic centimeters (about 1 fluid ounce or 2 cubic inches) of water. This is poured into the second pipette, and potassium hydroxide solution from the stock bottle is added until both arms of the pipette are a little more than half filled. The two solutions should be mixed in the pipette and the seal attached immediately to prevent absorption of the oxygen from the air. The mixing is done by raising and lowering the leveling bottle a few times and running gas into and out of the pipette.

Alkaline pyrogallic acid absorbs oxygen rapidly at first, but as oxygen is absorbed the speed of absorption decreases. The best results are obtained by renewing the solution whenever the absorption of oxygen becomes slow. One filling of the pipette can be used for about 40 determinations of oxygen in flue gas.

AMMONIACAL CUPROUS CHLORIDE SOLUTION FOR ABSORBING CARBON MONOXIDE.

The chemicals required for the preparation of a solution for the absorption of carbon monoxide are cuprous chloride, ammonium chloride, both small crystals, and ammonium hydroxide (ammonia water). The ammonia water should be clear and have a specific gravity of 0.91. The article sold in stores as household ammonia should not be used. It is best to purchase all the chemicals required from a chemical supply house.

A stock solution can be prepared best in a 2-quart bottle, which should be thoroughly cleaned before use. To 750 cubic centimeters (about 25 fluid ounces or 46 cubic inches) of water in the bottle is added 250 grams (about 9 ounces or 30 cubic inches) of ammonium chloride. The mixture is shaken until the salt crystals are dissolved. The ammonium salt dissolves readily and only a little shaking is necessary. To this solution is added 200 grams (about 7 ounces or 12 cubic inches) of cuprous chloride. The cuprous chloride dissolves slowly and the mixture should be shaken from time to time to aid solution.

Often the cuprous chloride does not all dissolve, and some of it settles on the bottom of the bottle. When the solution is being used, only the liquid should be poured off, without disturbing the sediment to any extent. A few pieces of clean scrap copper or copper wire placed in the bottle will help to keep the cuprous chloride reduced. If the bottle is tightly stoppered the solution can be stored indefinitely.

In preparing the stock solution for use enough is poured into the graduate or other glass vessel to fill one arm of the pipette. To this measured quantity is added slowly ammonium hydroxide (ammonia water). When the ammonia is poured in, a white flaky precipitate at first forms in the solution but disappears as more ammonia is added, and the solution becomes dark blue. The mixture should be stirred while the ammonia is added, and the amount of ammonia should be just enough to dissolve the precipitate completely.

Approximately one volume of ammonia is required for three volumes of the stock solution. If too much ammonia is added the ammonia vapor will increase the volume of the gas sample after contact with the solution. When all the precipitate has been dissolved the solution should be poured immediately into the pipette, as exposure to air weakens the solution. After the pipette has been filled according to the directions given in the section headed "Filling and Attaching Pipettes," any of the solution that may be left should be thrown away and not returned to the stock bottle.

A fresh solution of cuprous chloride, if given time enough, will remove all of the carbon monoxide from the gas mixture, but a solution

that has absorbed considerable carbon monoxide will not remove all of this gas from a gas mixture and may even give off carbon monoxide. Therefore the operator must know the condition of the solution in order to be certain of results.

The length of time the solution can be used with good results will depend on the volume of carbon monoxide to be determined. For small amounts of carbon monoxide a solution that has not previously absorbed much carbon monoxide should always be used. Because of the small amount of carbon monoxide ordinarily present in flue gas and the difficulty of making an accurate determination, it is not advisable to make this determination regularly in boiler-room work, especially if the CO_2 content of the gases is low.

FILLING AND ATTACHING PIPETTES.

To clean and fill a pipette it should be removed from the stand. The required quantity of solution is poured in the open end of the pipette and the latter then fixed in position on the stand. The solution should fill both arms a little more than half full, and when drawn up to the mark on the stem of the pipette it should stand in the rear arm to a depth of about 1 inch. The front arm of the pipette is attached to the header by a piece of black rubber tubing about 1¼ inches long. To make the connection the rubber tubing is slipped entirely over the small end of the pipette, the glass tubes are brought together, and the rubber tubing is worked carefully upward until half of it is on the glass tube from the header and half remains on the pipette. Wetting the inside of the rubber causes it to slide easily on the glass.

The solutions are drawn up to the mark on the stem of the pipette by lowering the leveling bottle before beginning an analysis. The seal should be attached to the pipettes as soon as they are filled in order to protect the solutions from the air. When the joints on the Orsat apparatus must be broken it is best to cut the rubber tubing, because after a short time the rubber sticks to the glass and does not slide easily.

Care should be taken not to get the solutions on the hands and clothes, as they are strongly alkaline and will injure the clothes. When handling potassium hydroxide sticks cotton gloves or a piece of cloth can be used to protect the hands.

CARE OF ORSAT APPARATUS.

The operator will save time and expense and prevent many troublesome difficulties by taking good care of the Orsat apparatus.

If the ground-glass surfaces of stop cocks are allowed to stand without cleaning, they will become cemented together by alkaline

solutions, and the cocks can not be operated. The only remedy is to keep the stopcocks free from alkali and lubricated with a thin film of vaseline. If too much vaseline is used, the openings in the cocks and capillary tubes become stopped with the excess. A properly lubricated stopcock has the appearance of a single piece of thick glass.

If a solution is accidently drawn into a stopcock, the cock should be removed at once and the surfaces wiped clean with a cloth or piece of soft paper, and lubricated with a thin film of vaseline. If necessary the header should also be removed and washed free from alkali.

The water in the burette and leveling bottle should be saturated with flue gas and should be changed as often as it becomes dirty. If the water becomes alkaline by solution being drawn into the header and washed into the burette it should be changed at once. If this is not done carbon dioxide will be absorbed by the alkaline water and the percentage of CO_2 indicated by the analysis will be low.

The joints made with rubber tubing should be examined and the apparatus tested for leaks before work is started. This is especially necessary when the Orsat apparatus is not used frequently.

The apparatus should be kept clean. If the walls of the burette and water jacket are dirty or dirty water is used, accurate measurements can not be made.

Skill in the use of the Orsat apparatus requires practice. However, an inexperienced but careful operator, after making about a dozen analyses can obtain results that are accurate enough for all ordinary requirements of boiler-room work.

USE OF GAS ANALYSIS IN REDUCING BOILER-ROOM LOSSES.

If gas analysis is intelligently applied to boiler furnaces it should prove itself an effective means of reducing boiler-room losses, for it furnishes information as to the magnitude and the cause of large chimney losses. An analysis for CO shows the approximate losses due to incomplete combustion. When efforts are made to reduce these losses, gas analysis shows how effective the applied remedies are.

Figure 21 is a graphic representation of the power-plant losses in an average industrial plant of 1,000 to 2,000 horsepower. The process of power generation, its transmission and utilization, is shown as a stream of heat starting with the coal fired under the boiler and ending in the power utilized in a cotton mill. The losses are shown as streams branching off to one side from the main stream. The first five side streams represent the boiler-room losses, and together amount to 43 per cent of the heat in the coal fired. The second loss, which is the heat carried away by the dry chimney gases, is the largest of boiler-room losses. It amounts to 26 per cent of the total heat in coal fired and is much larger than all the other boiler-room losses put

together. It is this loss that, by the intelligent interpretation of gas analysis, can be reduced to 15 or even 10 per cent without increasing appreciably the loss from incomplete combustion.

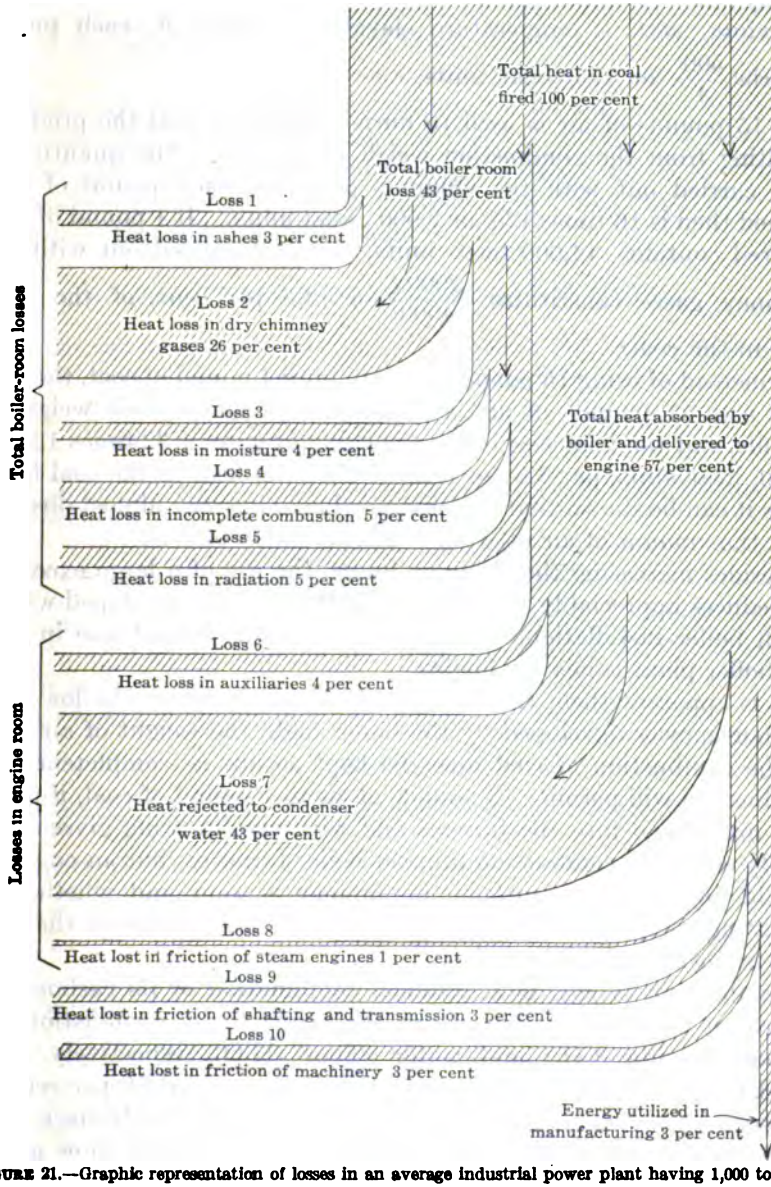


FIGURE 21.—Graphic representation of losses in an average industrial power plant having 1,000 to 2,000 horsepower capacity. The branches turning to the left from the main stream represent the losses.

For the complete combustion of 1 pound of coal in the ordinary boiler furnace about 15 pounds of air is necessary. This air is taken into the furnace at atmospheric temperature and leaves the boiler at

a temperature of about 500° F. higher. It carries along with it all the heat that has been absorbed in raising its temperature 500° F. Each pound of air or of the products of combustion absorbs approximately one-fourth of a heat unit per degree of temperature rise. Therefore, with a temperature elevation of 500° F. each pound absorbs $\frac{500}{4}$, or 125, heat units.

If 15 pounds of air is used to burn 1 pound of coal the products resulting from the combustion weigh 16 pounds. The quantity of heat carried out with the chimney gases for each pound of coal burned then is 16 times 125, or 2,000 , heat units. If 1 pound of coal as fired contains 14,000 heat units, the heat carried out with the chimney gases constitutes $\frac{2000}{14000}$, or 14.3 per cent, of the total heat in the coal.

If instead of using 15 pounds of air to burn 1 pound of coal, the fireman uses 31 pounds of air, the products of combustion weigh 32 pounds, and the heat loss in the dry chimney gases is 32 times 125, or 4,000, heat units, or 28.6 per cent of the total heat in the coal fired. Thus it can be shown that the chimney losses increase almost directly with the amount of air used for the combustion of coal.

Besides increasing the chimney losses, the use of a large excess of air reduces appreciably the horsepower that can be developed with a given boiler installation. This feature is an important one in case the boiler plant is heavily loaded.

It is apparent then, that if the chimney losses are to be low, and the horsepower developed by the boiler high, the weight of air used in the combustion of coal must be kept as low as completeness of combustion will permit; 15 pounds of air to 1 pound of coal, if properly introduced into the furnace and with careful firing gives practically complete combustion in most boiler furnaces, but an engineer should find out how much air his fireman is using and whether he is getting complete combustion. It is just this information that the analysis of flue gases furnishes.

Combustion of coal is a chemical combination of its carbon and hydrogen with the oxygen of air, the products of combustion are carbon dioxide (CO_2) and water vapor (H_2O) respectively. Air consists approximately of 20 per cent of oxygen and 80 per cent of nitrogen by volume. If all the oxygen that enters the furnace were used in combustion, the analysis of the products would show about 81.5 per cent of nitrogen and 18.15 per cent of carbon dioxide. The percentage of carbon dioxide would not be as high as the percentage of oxygen in the air admitted into the furnace because some of the oxygen combines with the free hydrogen of coal and forms water

vapor which is condensed and therefore does not appear in the analysis of gases.

If only one-half of the air entering the furnace is used in the combustion of coal the analysis of the products shows about 9 per cent of carbon dioxide and 10 per cent of free oxygen—that is, about half of the oxygen appears in the form of CO_2 and half as O_2. The CO_2 is not exactly equal to the O_2, because a small part of the oxygen used in combustion combines with the hydrogen of the coal and is condensed as water. Thus the CO_2 content of the flue gases shows what proportion of the air entering the furnace is actually used in the process of combustion and the oxygen content shows what proportion is in excess of the amount actually used.

CALCULATION OF THE WEIGHT OF GASES.

From the analysis the weight of the gases (W) per pound of coal burned can be computed from the following formula:

$$(1)\ W=\frac{11\ CO_2+8O_2+7(CO+N_2)}{3(CO_2+CO)}\times\frac{\text{per cent of carbon in coal}}{100}$$

Or, as $CO_2+O_2+CO+N_2=100$ always, with the simple Orsat analysis under consideration,

$$(2)\ W=\frac{(4\times CO_2+O_2+700)}{3(CO_2+CO)}\times\frac{\text{per cent of carbon in coal}}{100}$$

In applying equations *1* and *2* the percentages of CO_2, O_2, CO and N_2 in a given flue gas are to be substituted for the chemical symbols.

The following examples show the use of these equations:

Example A.

Suppose that the analysis of a given flue gas shows the following results:

	Per cent.
CO_2	7.0
O_2	12.0
CO	.2
N_2	80.8

Suppose the carbon content of the coal burned to be 85 per cent.

Substitution of the analytical results in equation *1* gives:

$$\frac{11\times7.0+8\times12.0+7(0.2+80.8)}{3(7.0+0.2)}\times\frac{85}{100}=\frac{740}{21.6}\times0.85=29.08 \text{ pounds of gases per pound of coal.}$$

Substitution of the analytical results in equation *2* gives:

$$4\times7.0+12.0+700\times\frac{85}{100}=\frac{740}{21.6}\times0.85=29.08 \text{ pounds of gases per pound of coal.}$$

Both equations give the same result; however, equation *2* is the simpler one to use.

Example B.

Suppose that the analysis of a given flue gas shows the following results:

	Per cent.
CO_2	12.0
O_2	7.0
CO	0.4
N_2	80.6

Suppose the carbon content of the coal burned to be 85 per cent.

Substitution of the analytical values in equation *1* gives:

$$\frac{11\times12.0+8\times7.0+7(0.4+80.6)}{3(12.0+0.4)}\times\frac{85}{100}=\frac{755}{37.2}\times0.85=17.27 \text{ pounds of gases per pound of coal.}$$

CALCULATION OF CHIMNEY LOSSES.

From the weight of gas per pound of coal the chimney losses can be computed by using the following equation:

(*3*) $W\times0.24\times(T-t)$=heat carried away with dry chimney gases expressed in British thermal units.

Where W=weight of gases in pounds per pound of coal as computed by equations *1* and *2*.

0.24=specific heat of gases.

T=temperature of gases leaving boiler, in °F.

t=temperature of air entering furnace, in °F.

If it is desirable to express this loss in percentage as given in figure 21, the value obtained by equation *3* is divided by the number of British thermal units in one pound of coal and multiplied by 100.

Thus in examples A and B if the temperature of air entering the furnace is 75° F., the temperature of the gases leaving the boiler 600° F., and the heat in the coal burned 13,500 British thermal units, the losses are:

$$(a)\ \frac{29.08\times0.24\times(600-75)\times100}{13,500}=27.1 \text{ per cent.}$$

$$(b)\ \frac{17.27\times0.24\times(600-75)\times100}{13,500}=16.1 \text{ per cent.}$$

In example A, with the CO_2 content in the flue gases 7.0 per cent, the loss is 27.1 per cent, and in example B, with 12 per cent of CO_2 in the flue gases, the loss is only 16.1 per cent of the heat in the coal, the difference being 11 per cent in favor of the furnace represented in example B having the high percentage of CO_2.

The two examples show that there is a definite relation between the percentage of CO_2 in the flue gases and the chimney losses represented in figure 21 by loss 2. This relation is shown in figure 22 in which the horizontal distances represent the percentages of CO_2 in flue gases and the vertical distances (the ordinates) represent the heat losses in dry chimney gases. Each of the four curves gives the heat losses for one temperature difference between the flue gases and the air entering the furnace, as indicated by the figures at the right of the curves.

The curves are computed for coal having 82 per cent of carbon and a heat value of 13,500 British thermal units; that is, a good grade of bituminous steam coal.

The following examples show how figure 22 can be used for computing dry chimney gas losses, when the percentage of CO_2 and the temperature of the flue gases and of the boiler-room air are determined.

EXAMPLE A.

CO_2 in flue gases	=6.0 per cent.
Temperature of flue gases	=600° F.
Temperature of boiler-room air	=75° F.

The difference between the flue gas and the boiler-room temperature is 600°−75°=525° F. Therefore the second curve from the top, designated by the figures 525° F., should be used for this example. Take the vertical line starting from the point of 6.0 per cent of CO_2 on the scale at the bottom of the chart and follow it to the second curve from top; from the intersection point on this curve follow a horizontal line to the scale at the left, which gives the losses directly in percentage of the heat in the coal. In this case the losses in the dry chimney gases are found to be 31.5 per cent of the heat in the coal.

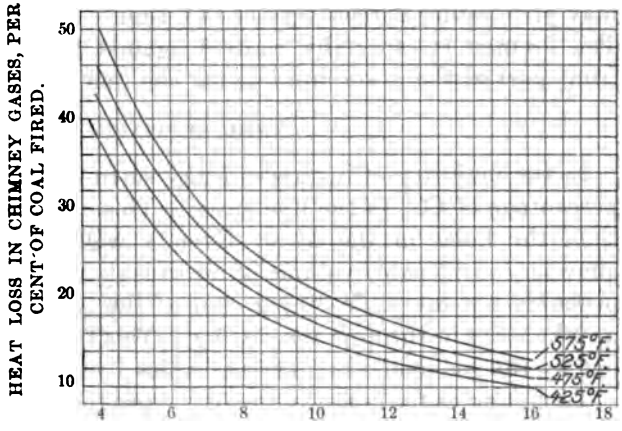


FIGURE 22.—Relation between the percentage of CO_2 in the flue gases and the heat lost in the dry chimney gases. Each of the curves gives this loss for one temperature difference between the flue gases and the air entering the furnace as indicated by the figures at the right of each curve.

EXAMPLE B.

CO_2 in flue gases	=14.0 per cent.
Temperature of flue gases	=650° F.
Temperature of boiler-room air	=75° F.

The temperature difference between the flue gases and the boiler-room air is 575° F. Therefore the top curve should be used for this example.

Follow the vertical line of 14 per cent of CO_2 to the highest curve and from the intersection point a horizontal line to the scale at the left. The heat loss in the dry chimney gases is found to be 15 per cent.

The general characteristic of the curves is that as the CO_2 in the flue gases increases, the heat loss in the dry chimney gases decreases, at first very rapidly, but this decrease becomes small in the region of a high percentage of CO_2. For ordinary boiler furnaces probably it does not pay to run the CO_2 higher than 10 or 12 per cent. In many cases the leakage in the setting is such that the attainment of even 10 per cent is impossible.

CAUSES OF LOW CO_2 CONTENT.

The two principal causes of a low percentage of CO_2 are holes in the fire and leaky settings.

HOLES IN FIRES.

Technical Paper 80[a] describes the condition under which holes are formed in the fires, and points out the precautions that the fireman should use to prevent their formation. It suffices to repeat here that by firing small charges at short intervals of three to six minutes and by placing the fresh coal on the thin spots the formation of holes in the fuel bed can be prevented. It is not necessary to keep the fuel bed thicker than 5 or 6 inches. In fact, a 5-inch fuel bed if kept level may give higher percentages of CO_2 than a fuel bed 12 inches thick. The fireman is especially warned against heaping the coal on the front part of the grate and leaving the rear part uncovered.

LEAKY SETTINGS.

In the majority of instances leaky settings are the cause of a low percentage of CO_2 in the flue gases. This cause is harder to remove than the holes in the fires. Even a well-cared-for boiler setting allows a considerable volume of air to leak in. In the average plant probably not less than 30 per cent of the gases passing through the uptake leaks in through the setting. This feature is forcibly brought out by the gas analyses given in Tables 1 and 2 (pp. 51 and 52).

Table 1 gives the composition of the products of combustion as they pass through the uptake. Table 2 gives their composition as they enter a Heine boiler. The setting was seemingly in good condition; all the cracks as well as the joints between metal and brick wall were carefully packed with asbestos rope and the walls were painted with thick asphalt paint. In spite of all these precautionary measures considerable air entered the setting, as a comparison of the average values of the two tables shows. No serious objection can be made against the method of sampling the gases. Both sets of samples were collected simultaneously.

Similar difficulties are discussed in Bulletin 23.[b] All these data would seem to indicate that in plants where little attention is given to boiler settings the air leakage must be large indeed, and that it is important to keep boiler settings free from leaks as far as practicable if large chimney-gas losses are to be avoided.

In individual instances such losses can be approximately ascertained by taking simultaneous samples near the furnace, before the gases are diluted with the leakage, and in the uptake. It is advisable

[a] Kreisinger, Henry, Hand firing soft coal under power-plant boilers: Tech. Paper 80, Bureau of Mines, 1915, 83 pp.

[b] Breckinridge, L. P., Kreisinger, Henry, and Ray, W. T., Steaming tests of coal and related investigations, Sept. 1, 1904, to Dec. 31, 1908: Bull. 23, Bureau of Mines, 1912, pp. 289-293.

to take several sets of samples, the sampling tube being placed each time at a different point of the same cross section of the gas path. In estimating the leakage all sets of samples should be given consideration.

USE OF WATER-COOLED SAMPLER.

For the collection of a gas sample near the furnace it may be necessary to use a water-cooled sampler similar to the one shown in figure 23. Additional details of construction are shown in figure 27. Whenever possible this sampler should be used in a horizontal position. When used in this manner the trouble of the sampler becoming stopped with water condensation, soot, and tar will be greatly reduced.

The water inlet of this sampler must be connected to a cold-water supply of about 25-pounds pressure with a ½-inch garden hose, and

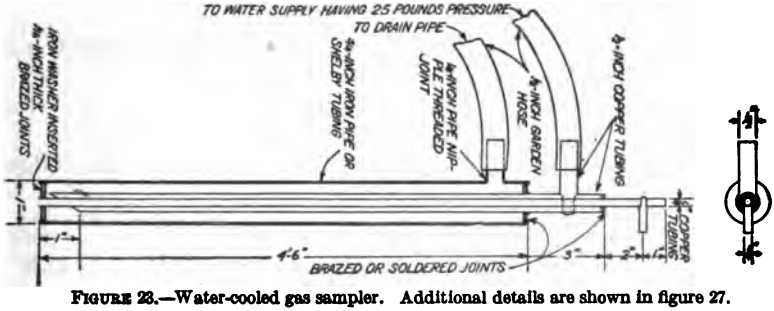


FIGURE 23.—Water-cooled gas sampler. Additional details are shown in figure 27.

the discharge from the sampler should be similarly connected to a drain. Both hose connections should be long enough to permit the sampler being inserted into or withdrawn from the furnace while the water is flowing through.

LOSSES FROM INCOMPLETE COMBUSTION.

In figure 21 the fourth side stream represents the total losses from incomplete combustion. By analyzing the flue gases for CO_2, O_2, and CO, the incomplete-combustion losses due to carbon burning to CO instead of to CO_2 can be determined. Such losses constitute perhaps one-half of the total incomplete-combustion losses. When 1 pound of carbon burns to CO_2, the combustion generates 14,500 British thermal units; when it burns to CO, only 4,500 heat units are generated. Thus 10,000 heat units are lost for every pound of carbon burning to CO. The gas analysis and the percentage of carbon in the coal furnish data for the computation of how much of the carbon in the coal fired burns to CO. With this quantity determined the heat loss due to this part of incomplete combustion can be obtained by multiplying by 10,000, which in round numbers is the heat value of 1 pound of carbon in the form of CO.

CALCULATION OF LOSSES DUE TO THE ESCAPE OF CO IN FLUE GASES.

The following are general formulas for the calculation of losses due to CO in flue gases:

(4) $$W=\frac{CO}{CO \text{ and } CO_2}\times\frac{C}{100}$$

where W=weight of carbon in pounds burned to CO for each pound of coal fired.

CO=percentage of CO in flue gases.

CO_2=percentage of CO_2 in flue gases.

C=percentage of carbon in coal.

(5) $$H=W\times 10{,}200$$

where H=heat loss in B. t. u. per pound of coal.

10,200=heat value in B. t. u. of 1 pound of carbon in the form of CO when burned to CO_2.

(6) $$L=\frac{H}{Q}$$

where L=the heat loss due to carbon burning to CO, expressed in percentage of heat in coal.

Q=heat value in B. t. u. per pound of coal.

The following examples show the method of calculating the heat losses due to CO in flue gases.

Example A.

Suppose that the analysis of a given flue gas shows the following results:

	Per cent.
CO_2	7.0
O_2	11.2
CO	0.8

Suppose the carbon content of the coal burned to be 82 per cent. The heat value of 1 pound of the coal is 13,500 B. t. u.

Substitution of the values given by the analysis in equation 4 gives:

$W=\frac{0.8}{0.8+7.0}\times\frac{82}{100}=0.084$ pound of carbon burned to CO for each pound of coal fired.

$H=0.084\times 10{,}200=857$ B. t. u. lost per pound of coal burned.

$L=\frac{857\times 100}{13{,}500}=6.3$ per cent of the heat in coal fired is lost in CO.

Example B.

Suppose that the analysis of a given flue gas gives the following results:

	Per cent.
CO_2	12.0
O_2	5.6
CO	1.4

Suppose the carbon content of the coal burned to be 82 per cent. The heat value of 1 pound of the coal is 13,500 B. t. u.

Substitution of the values given by the analysis in equation 4 gives:

$W=\frac{1.4}{1.4+12.0}\times\frac{82}{100}=0.085$ pounds of carbon burned to CO for each pound of coal fired.

$H=0.085\times 10200=867$ B. t. u. lost per pound of coal.

$L=\frac{867\times 100}{13{,}500}=6.4$ per cent of the heat in coal fired lost in CO.

The two specific examples show that the heat loss due to carbon burning to CO instead of CO_2 depends not only on the percentage of CO in flue gases but also on the CO_2 content. This fact is shown more clearly in figure 24 which shows the relation between the percentage of CO in the flue gases and the heat losses due to the escape of CO. Each of the curves gives this loss for one constant percentage of CO_2, as indicated by the figures under the curves. The curves are compiled for coal containing 82 per cent of carbon and having a heat value of 13,500 B. t. u. It is apparent from the position of these curves that the higher the percentage of CO_2 the lower is the heat loss for the same percentage of CO. Thus, with 1 per cent of CO and

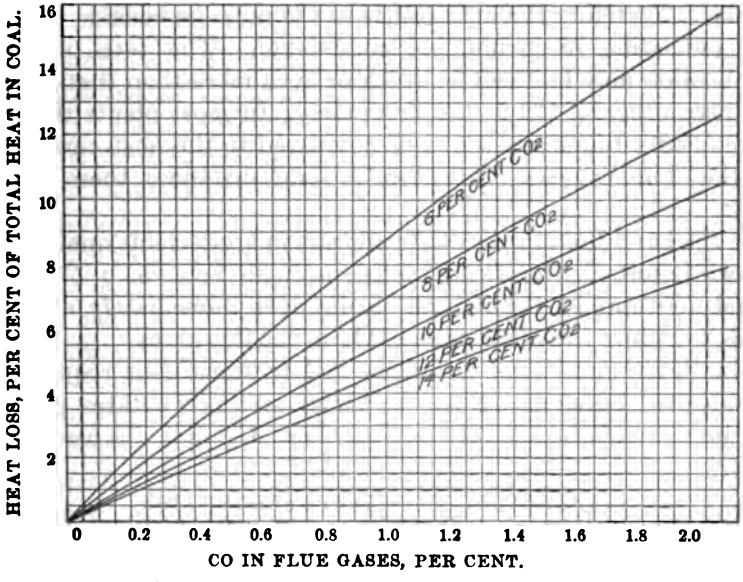


FIGURE 24.—Relation between the percentage of CO in the flue gases and the heat losses due to the escape of CO. Each curve gives the loss for one constant percentage of CO_2 as indicated under each curve.

6 per cent of CO_2, the loss is 8.8 per cent of the total heat in the coal, whereas if the percentage of CO_2 in the gases is 14, 1 per cent of CO causes only 4.2 per cent heat loss.

The curves of figure 24 can be used for computing approximately the incomplete combustion losses due to CO in flue gases. Thus, example A, on page 42, can be worked out as follows:

The vertical line starting from the point of 0.8 per cent at the bottom of the chart is followed to a point somewhat less than halfway between the curves of 8 and 6 per cent of CO_2. From this point a horizontal line is followed to the scale at the left which gives the heat losses for this example to be about 6.3 per cent, or the same as computed by the arithmetic.

Example B is worked out by means of the chart as follows:

From the point of 1.4 per cent of CO at the bottom of the chart follow the vertical line to the curve of 12 per cent of CO_2. From the intersection point of this curve follow the horizontal line to the scale at the left, which gives the losses to be about 6.4 per cent, or about the same as computed in the example.

Attention is called to the fact that CO constitutes only a part of the incomplete combustion losses. In burning soft coal when CO appears there are usually some hydrogen and gaseous hydrocarbons as well as tar vapors and soot escaping through the chimney along with CO. The tar vapors and soot form a large part of the visible smoke. Therefore the appearance of CO must be considered as only one indication of incomplete combustion. The total incomplete combustion may be twice as much or even more than that shown by the percentage of CO in the flue gases. In most plants the incomplete combustion losses are small compared to the heat carried away by the chimney gases; however, in some instances, these losses are great.

In the hand-fired furnaces CO appears in appreciable quantities one or two minutes after firing, as is shown in Table 5 (p. 57). Additional air supplied through the firing door immediately after firing tends to reduce the percentage of CO in the flue gases.

The determination of hydrogen and hydrocarbons requires more complicated apparatus than the Orsat and necessitates great skill on the part of the operator. Therefore it is not discussed in this report.

CAUSES OF INCOMPLETE COMBUSTION.

The chief causes of incomplete combustion are an insufficient supply of air admitted above the fuel bed and lack of proper mixing of this air with the combustible rising from the fuel bed. Perhaps in ordinary boiler furnaces the lack of proper mixing is more often the cause of incomplete combustion than the insufficient supply of air.

The amount of air introduced into the furnace, both through the grate and the firing door, can be approximately determined by the analysis of a gas sample taken in the furnace, or in some other place within the setting before the gases are diluted by the air leakage through the setting. Such samples should be collected with a water-cooled sampler similar to that shown in figure 23.

Several samples must be collected and analyzed, and the conditions of fire under which the samples are collected must be carefully observed and considered before the true condition of the combustion can be ascertained. Air leaking into the setting beyond the furnace seldom helps the combustion if combustible material is contained in the gases, because the temperature is usually too low for the ignition

and burning of the combustible material. Therefore the analysis of a gas sample collected in the uptake may show both incomplete combustion and a large excess of air. In the average plant, if reasonable care is taken of the boiler setting, 10 to 12 per cent of CO_2 in the flue gases gives about the best results as regards excess of air and incompleteness of combustion.

In some plants the CO_2 may reach as high as 14 per cent with only traces of incomplete combustion, whereas in other plants even 8 per cent of CO_2 may be accompanied with a considerable loss from incomplete combustion.

DESIRABILITY OF ANALYZING FLUE GASES.

The question may be asked, Is it desirable in all steam plants to analyze flue gases? In general, it can be said that it is desirable. Whether the gases should be sampled and analyzed continuously or periodically depends perhaps on the size of the plant and the nature of the load. In some of the large plants generating power 24 hours a day gases are sampled and analyzed continuously, and the fireman is paid a bonus according to how good a combustion he is able to obtain, the quality of the combustion being determined by analysis of the flue gases. The gas samples are analyzed either with an Orsat apparatus or with an automatic CO_2 recorder. This plan should be tried wherever it appears at all feasible.

In some plants, particularly those of smaller capacity and those operating with full load only during the day hours, it may perhaps not be practicable to sample and analyze gases continuously. In such plants gas sampling and analyzing should be applied long enough to determine definitely the prevailing furnace conditions and the efficiency of the methods of firing. When such determination has been made the proper remedies to increase the efficiency of the steam plant can be applied. In hand-fired plants such remedies consist chiefly of getting the fireman into the habit of firing small charges at short intervals and keeping the fuel bed free from holes by placing the fresh coal on the thin spots. Small and frequent firing makes the amount of combustible rising from the fuel bed nearly uniform and proportional to the constant air supply, so that incomplete combustion is thus reduced to a minimum. By keeping the fuel bed free from holes a large excess of air in the furnace is avoided. Stopping air leakages into the setting further helps in reducing the excess of air. After the efficient firing has been well established and the boiler settings put into good condition, the analyzing of the gases may be stopped and used only at intervals to check the fireman and to find whether the settings remain in good condition.

EXPERIMENTAL RESULTS OF SAMPLING AND COLLECTING FLUE GASES.

The recommendation of the methods of sampling and collecting flue gases already described are based on experimental data. Some of these data have been accumulated during investigations of the combustion of coal; other data have been obtained from experiments made especially for the purpose of obtaining information on the subject of sampling and collecting flue or furnace gases. Inasmuch as these data show plainly what accuracy can be expected when

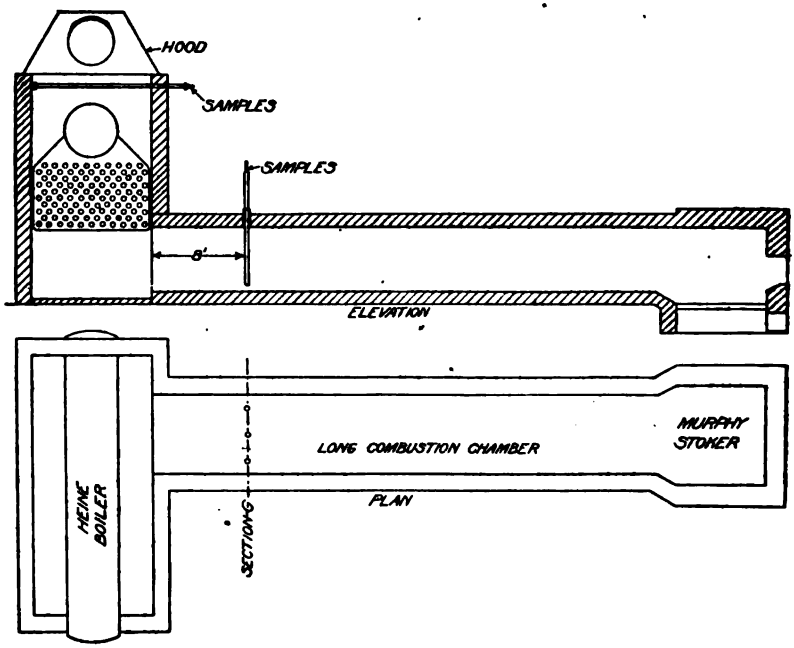


FIGURE 25.—Outline of experimental furnace with long combustion chamber connected to a Heine boiler. Section G in long combustion chamber is 8 feet from the entrance of gases into the Heine boiler.

flue gases are being sampled with various devices, the data are here presented and discussed.

The experiments, according to what they are intended to illustrate, are grouped into three classes, as follows:

(*a*) Experiments with different devices for sampling gases in water-tube and fire-tube boilers.

(*b*) Experiments showing the difficulty of collecting gases at a uniform rate over periods of three to five hours.

(*c*) Experiments on the absorption of CO_2 by water and brine used in collecting bottles.

EXPERIMENTS ON SAMPLING FLUE GASES.

Three series of tests were made to determine when the open-end single-tube sampler can be relied on to collect approximately the average sample, and when it is advisable to use the perforated tube sampler or some other more complex device. The first series of tests was made on a Heine boiler into which were discharged the hot products of combustion from a special experimental furnace. This furnace consisted essentially of a Murphy stoker, with a grate area of 25 square feet, and a combustion chamber 3 by 3 feet in cross section and about 45 feet long. The end of the combustion chamber was connected to the side of the boiler. The outline of the combined apparatus is shown in figure 25.

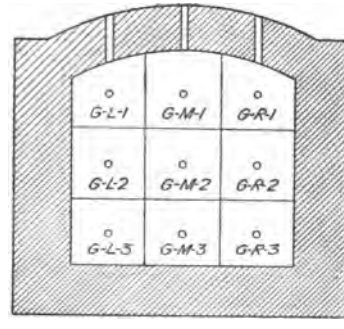


FIGURE 26.—Placing of samplers at section G of the long combustion chamber.

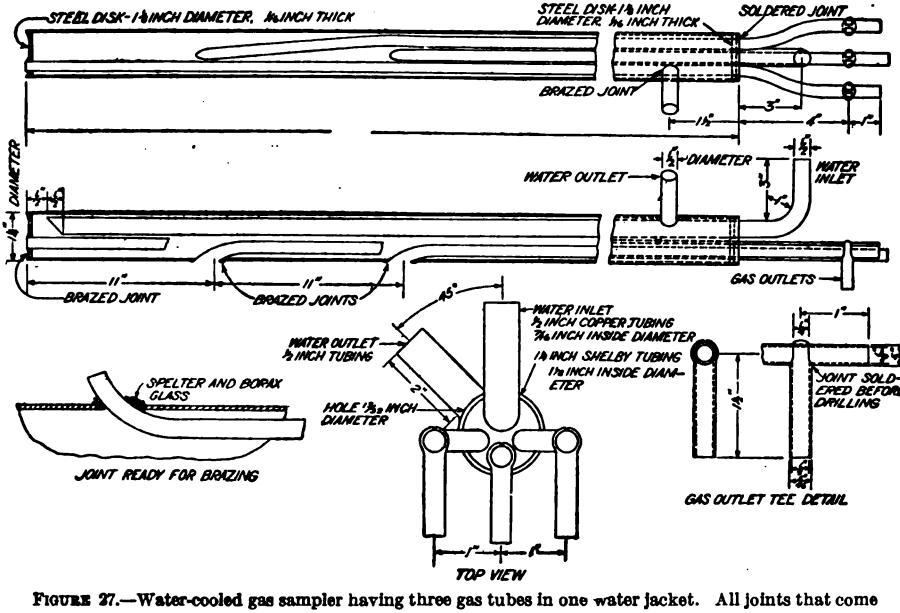
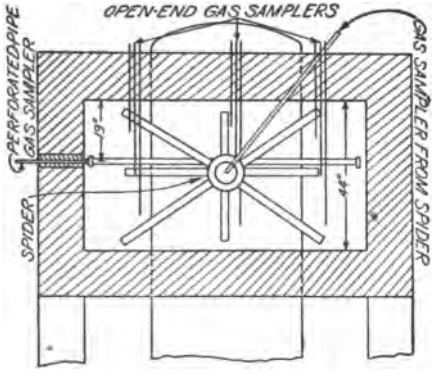


FIGURE 27.—Water-cooled gas sampler having three gas tubes in one water jacket. All joints that come in contact with flames are brazed; joints that remain outside of the furnace are soldered. When the sampler is being brazed or soldered, it should be held in such a position that the molten spelter or solder runs into the joint; this is important if good joints are to be obtained. When the joints to be brazed are being fitted, care should be taken to have the end of the copper tubing extend out far enough so that the spelter will not run down into it. After the joint has been brazed, the protruding end of the copper tube can be filed off. The side outlets on the gas tubes are first fitted as shown and then soldered by placing a piece of solder into the side outlet and heating the joints over a gas-torch flame, the side outlet being held up so that the molten solder runs all around the joint. The hole between the side outlet and the gas tube is drilled after the joint has been soldered. The gas sample is drawn through the side outlet, and the opening at the end of the gas tube is closed with a piece of rubber tubing and a glass plug and is used only when the tube is being cleaned after it has become stopped with soot.

The products of combustion were sampled at section G just before they entered the boiler and again in its uptake, where three different sampling devices were installed. At section G nine open-end sampling tubes were placed as shown in figure 26, so that each tube sampled gases from approximately 1 square foot of cross-sectional area.



SECTION A-B

The sampling tubes were inserted through the holes in the arch. The samplers were water cooled, three tubes being inclosed in one water jacket as shown in figure 27. Through each of the sampling tubes the gas was collected into a separate gas holder.

In the uptake were placed nine open-end sampling tubes, one perforated sampler, and a special sampling device, which, on account of its shape, was called a "spider." The placing of these devices is shown in figures 28, 29, and 30.

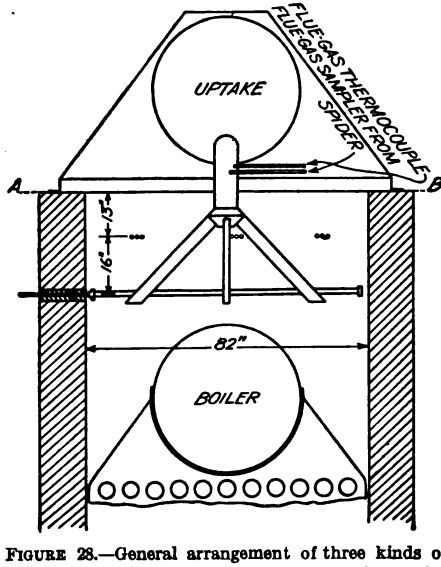


FIGURE 28.—General arrangement of three kinds of sampling devices in the uptake of a Heine boiler connected to long combustion chamber.

The open-end tubes consisted of standard ¼-inch pipe. They were inserted into the uptake through three holes in the rear wall.

The perforated-tube sampler was of the same design as that shown in figure 5. It consisted of a piece of 1¼-inch pipe 7 feet long, closed at both ends. The small tube extending to its center was standard ¼-inch pipe. The perforations were one-sixteenth of an inch in diameter and 3 inches apart. This sampler was inserted into the uptake through a hole in the side wall.

The "spider" was a device for obtaining the average sample and the average temperature of flue gases. It was made of No. 20 galvanized sheet iron. The details of its construction are shown in figure 31.

The gas entered the device through the long narrow opening in the bottom of the "legs." The streams of gas from the eight legs came together in the conical body and left through the 6-inch pipe bent into the breeching. A ¼-inch pipe was inserted into the center of the 6-inch pipe for drawing the sample. Immediately above this ¼-inch pipe was placed the junction of a thermocouple for measuring the temperature of the flue gases.

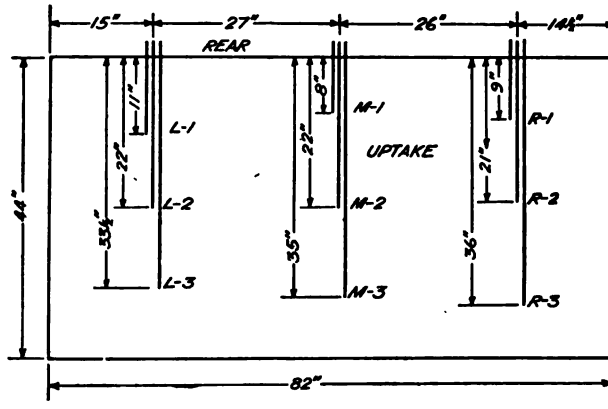


FIGURE 29.—Placing of nine open-end samplers in uptake of Heine boiler.

Each of the nine open-end sampling tubes, the perforated sampler, and the ¼-inch pipe taking gas out of the "spider" were connected to separate gas-collecting devices, one of which is shown in figure 32.

The collecting devices were connected with a 1¼-inch pipe to a strong steam ejector which caused a continuous stream of gas to flow through each of the sampling tubes. The gas streams were caused to bubble through the water in the wash bottle, so that if any of the sampling tubes became clogged the bubbling in the wash bottle ceased. Thus no sample could be missed without the operator knowing it. The gas was collected over mercury in glass holders of 125 c. c. capacity. The design of the gas holder is given in Plate I, which shows a table and equipment for collecting nine samples.

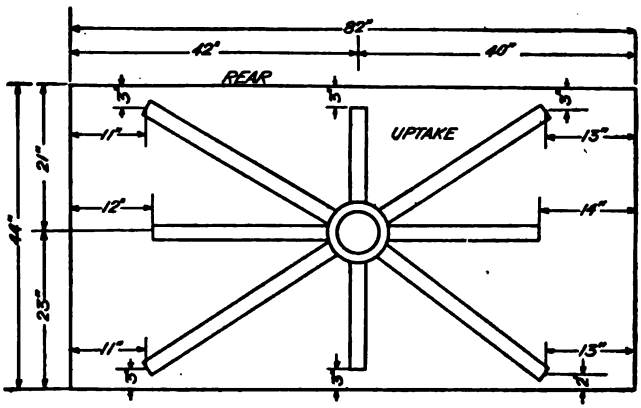


FIGURE 30.—Placing of the "spider" in uptake of Heine boiler.

The gas holders are mounted in wooden stands, each of which contains three gas holders. The figure shows one of the stands removed,

so that the wash bottles and their connections may be seen more clearly.

All samples were collected simultaneously and the time of collecting them was about 20 minutes.

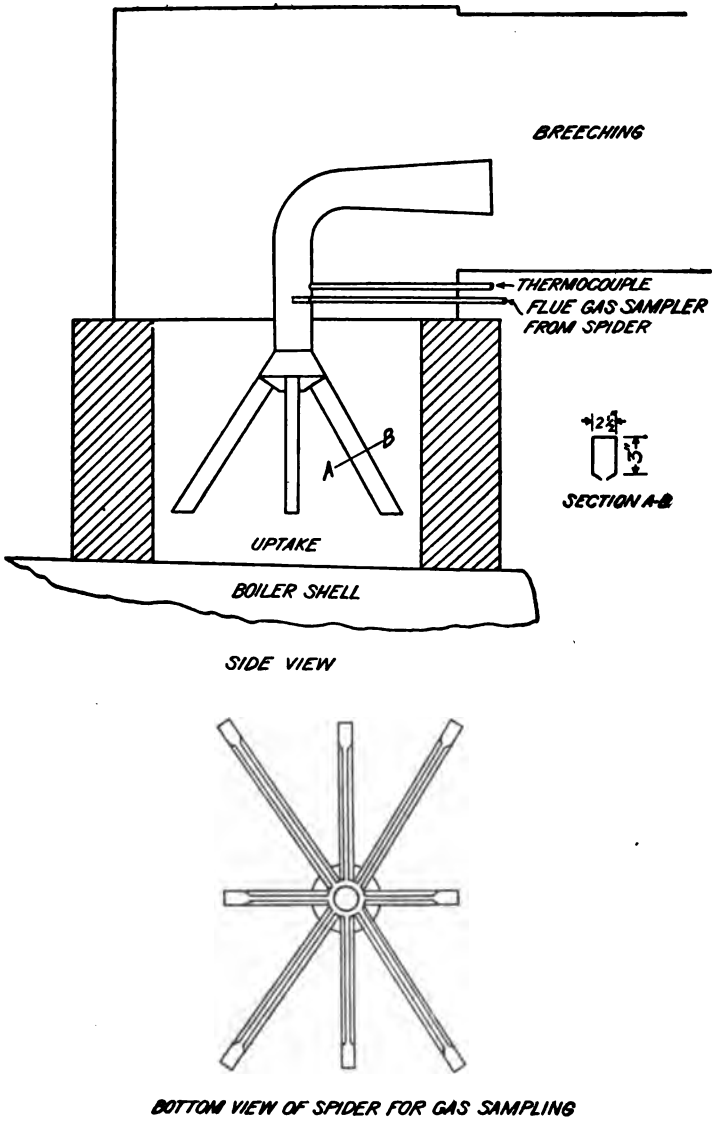
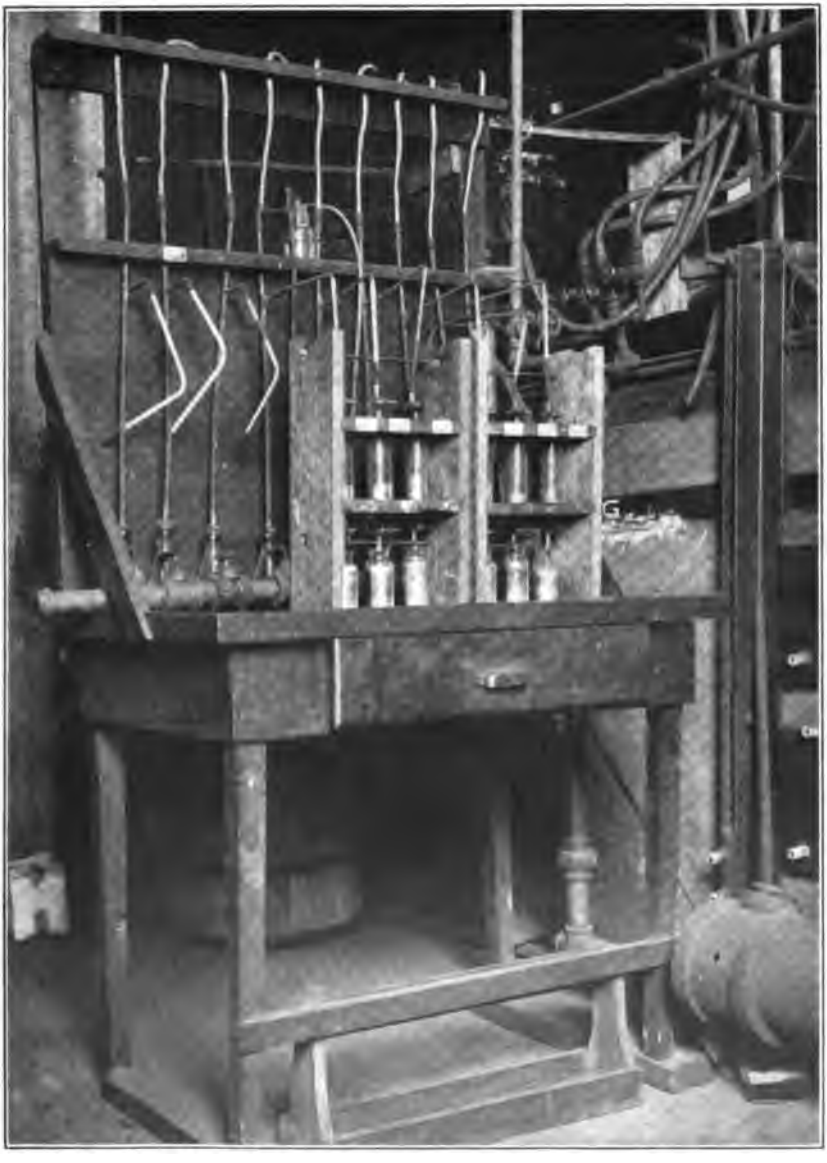


FIGURE 31.—Details of construction of "spider." Bottom view shows openings through which gases enter "spider." Side view shows placing of "spider" with respect to hood and breeching.

Tables 1 and 2 following show the composition of eight sets of simultaneous samples collected from the Heine boiler connected to the experimental long combustion chamber.



EQUIPMENT FOR COLLECTING NINE SAMPLES OF FLUE GASES.

The nine samples can be identified by reference to figure 29. The test number refers to the test with the experimental furnace.

TABLE 1.—*Results of analyses of samples taken in the uptake of a Heine boiler.*

Sample.[a]	Test 185.		Test 186.		Test 187.		Test 188.	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
L-1	5.8	14.2	7.9	11.7	8.9	10.4	8.7	10.8
L-2	5.9	13.9	7.9	11.8	8.9	10.3	9.1	10.2
L-3	5.5	14.5	8.3	11.4	9.3	9.7	9.8	9.6
M-1	5.7	14.3	7.6	12.0	8.8	10.7	8.7	10.7
M-2	5.7	14.4	7.9	11.7	8.7	10.5	8.8	10.6
M-3	5.5	14.5	8.1	8.2	9.1	9.9	8.8	10.4
R-1	6.7	13.0	9.8	9.5	9.8	9.6	9.7	8.9
R-2	6.0	14.0	8.7	10.8	10.1	9.0	9.9	9.4
R-3	5.0	15.0	7.4	12.3	8.3	11.3	8.3	11.3
Average	5.75	14.2	8.2	11.0	9.1	10.2	9.1	10.2
Maximum variation	5.0 to 6.7	.....	7.4 to 9.8	.....	8.3 to 10.1	.....	8.3 to 9.9	.....
(b)	5.6	14.6	8.1	11.4	8.9	10.3	8.8	10.5
(c)	5.5	14.1	8.4	11.2	9.2	10.0	9.4	10.0

Sample.[a]	Test 189.		Test 190.		Test 192.		Test 193.	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
L-1	9.0	10.7	8.4	11.0	11.0	8.0	11.3	6.8
L-2	10.1	9.4	9.2	10.2	10.6	8.7	9.7	9.3
L-3	10.9	8.1	10.6	8.6	9.7	9.8	10.1	8.8
M-1	8.8	9.1	9.0	10.3	9.3	9.6	9.9	9.0
M-2	9.9	9.7	9.3	9.8	9.9	9.2	10.7	8.2
M-3	9.4	9.9	9.2	10.1	9.8	9.8	10.5	8.5
R-1	11.1	7.2	10.5	8.8	9.2	10.4	9.5	9.1
R-2	11.1	7.9	10.2	8.8	10.3	9.7	11.0	7.8
R-3	9.1	10.5	8.2	11.3	11.5	8.8	11.9	6.7
Average	9.9	9.2	9.4	9.9	10.1	9.3	10.5	8.2
Maximum variation	8.8 to 11.1	.....	8.2 to 10.6	.....	9.2 to 11.5	.....	9.5 to 11.9	.....
(b)	.....	.....	9.1	10.2	9.5	9.5	10.5	8.3
(c)	10.1	9.4	9.5	9.9	.....	.....	.....	.....

[a] See figure 29, p. 49. [b] Sample taken with "spider." [c] Sample taken through 1¼-inch perforated pipe.

TABLE 2.—*Results of analyses of samples collected at section G of long combustion chamber.*

Sample.[a]	Test 185.			Test 186.			Test 187.			Test 188.		
	CO_2	O_2	CO	CO_2	O_2	CO	CO_2	O_2	CO	CO_2	O_2	CO
G-L-1	8.5	10.8	0.0	12.8	5.9	0.0	14.2	4.4	0.0	14.8	3.5	0.3
L-2	8.8	10.8	.0	12.9	6.2	.0	14.1	4.4	.0	15.0	3.5	.2
L-3	9.0	10.5	.0	13.3	5.6	.0	14.7	3.8	.0	14.9	3.6	.3
G-M-1	9.2	10.4	.0	13.0	5.6	.1	14.4	3.9	.0	14.8	3.6	.3
M-2	9.3	10.3	.0	13.1	5.6	.0	14.0	4.4	.0	14.1	4.3	.2
M-3	9.3	10.2	.1	13.2	5.7	.1	13.1	5.3	.0	14.9	3.6	.3
R-1	5.6	14.5	.0	11.5	7.5	.0	13.7	5.1	.0	13.1	5.4	.1
R-2	9.8	9.7	.0	13.2	5.7	.0	14.3	4.2	.0	15.0	3.4	.3
R-3	10.0	9.5	.0	13.4	5.6	.0	13.4	5.5	.0	14.8	3.5	.4
Average	8.8	10.7	.0	12.9	5.9	.0	14.0	4.6	.0	14.6	3.8	.3
Maximum variation	5.6 to 10.0	.....	.....	11.5 to 13.4	.....	.....	13.1 to 14.7	.....	.....	13.1 to 15.0	.....	.....

[a] See figure 26, p. 47.

TABLE 2.—*Results of analyses of samples collected at section G of long combustion chamber*—Continued.

Sample.[a]	Test 189.			Test 190.			Test 192.			Test 193.		
	CO_2	O_2	CO	CO_2	O_2	CO	CO_2	O_2	CO	CO_2	O_2	CO
G-L-1	14.6	4.1	0.0	14.3	4.3	0.0	13.5	4.9	0.0	13.7	4.7	0.0
L-2	14.6	3.8	.0	14.0	4.1	.0	13.9	4.3	.2	13.5	4.9	.0
L-3	14.6	4.0	.0	14.0	4.5	.0	13.3	5.3	.1	13.5	5.0	.1
G-M-1	14.7	3.6	.0	14.2	4.2	.0	14.3	3.9	.0	14.2	3.7	.0
M-2	[b].6	[b]20.2	.0	12.3	5.5	.0	15.2	2.4	.0	14.6	3.8	.0
M-3	14.7	4.0	.0	13.8	4.9	.0	11.3	7.2	.3	12.5	5.9	.0
R-1	12.5	6.5	.0	12.5	6.1	.0	11.1	7.8	.0	14.7	3.6	.1
R-2	14.8	3.5	.0	14.3	4.2	.0	14.9	3.4	.1	14.6	3.6	.0
R-3	15.0	3.4	.0	14.0	4.4	.0	15.1	3.3	.1	15.0	3.4	.0
Average	14.4	4.1	.0	13.7	4.7	.0	13.6	4.7	.1	14.0	4.3	.0
Maximum variation	12.5 to 15.0	.....	.0	12.3 to 14.3	.....	.....	11.1 to 15.2	.....	.....	12.5 to 15.0	.....	.....

[a] See figure 26, p. 47. [b] Not included in average; leakage in tube.

Table 1 shows that with the boiler equipment used the center sample, designated M-2, came as near to the average as the "spider" sample or the sample taken through the perforated tube. Therefore, with similar installations it would be safe to use the open-end tube placed in the center of the cross sections of the uptake.

As shown by the analysis of the samples collected at section G (Table 2), the gas is of a fairly uniform composition when it enters the boiler. The uniformity is undoubtedly the result of the long travel of the gas through the unusually long combustion space of the experimental furnace which gives the gases an opportunity to mix. If the gases enter the boiler uniformly mixed, it is to be expected that they leave it in a similarly uniform composition. It is only the air leakage into the boiler setting that could possibly destroy such uniformity of composition. Comparison of the analyses of gases collected in the uptake with those of the gases collected at section G will indicate that a considerable amount of air leaked into the setting. However, the mixing of the gases as they pass among the boiler tubes is such that the gases come out nearly uniformly diluted with air over the entire cross section of the uptake.

To determine whether the mixing of the gases as they pass through the boiler is sufficient to cause a uniform gas mixture in the uptake, a set of nine open-end sampling tubes and one perforated tube was placed in the uptake of a Heine boiler equipped with a Jones underfeed stoker. The stoker was placed directly under the boiler as in the standard commercial installation. The gases passed first under the boiler to the rear, then among the boiler tubes to the front, and then under the steam drum to the uptake in the rear of the boiler. The placing of the sampling tubes is shown in figure 33. The tubes were connected to the same gas-collecting apparatus as shown in figure 32 and Plate I.

Four sets of samples were collected in this installation. The time of collecting the samples was about 15 minutes. The analyses of the samples are given in Table 3. The table shows that the mixing of the gases as they pass among the boiler tubes is such that the

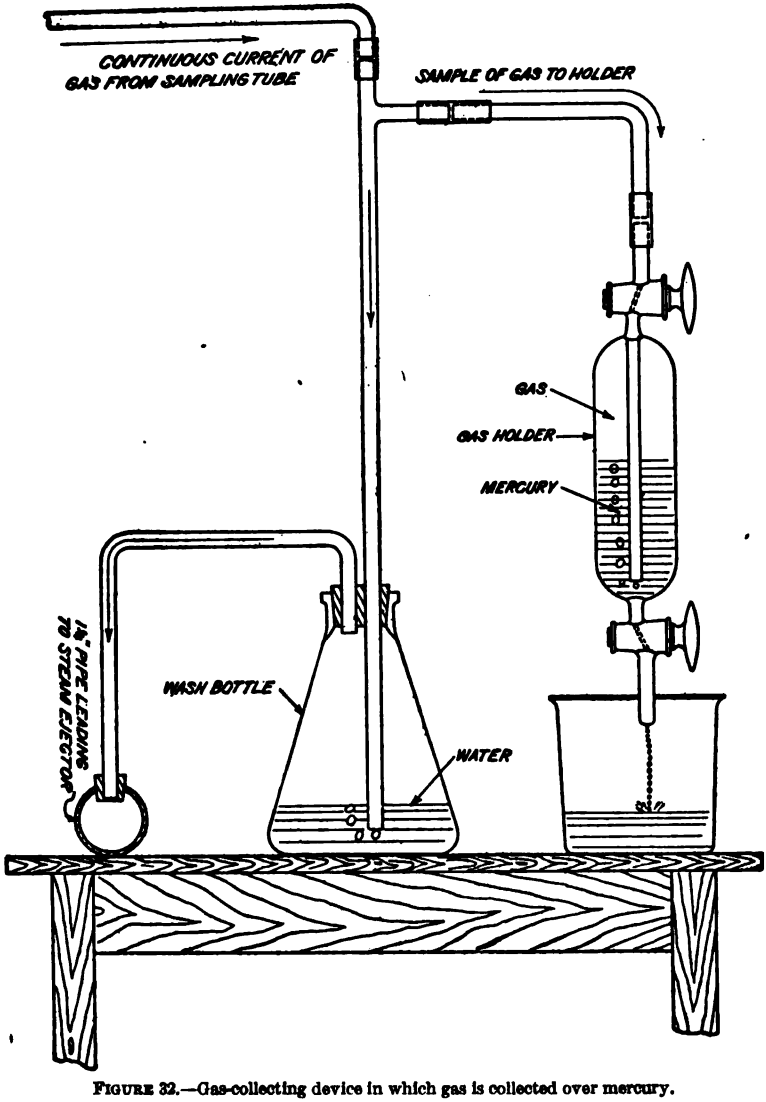


FIGURE 32.—Gas-collecting device in which gas is collected over mercury.

gas mixture in the uptake is fairly homogeneous. The composition of the sample collected with the central open-end tube was nearly the same as that of the sample collected with the perforated sampling tube, and both were close to the average of the nine samples.

TABLE 3.—*Results of analyses of samples taken in uptake of a Heine boiler equipped with Jones underfeed stoker.*

Sample.[a]	Set 1.				Set 2.			
	CO_2.	O_2.	CO.	$CO_2 + O_2 + \frac{1}{2}CO$.	CO_2.	O_2.	CO.	$CO_2 + O_2 + \frac{1}{2}CO$.
L-1	6.0	13.6	0.0	19.6	9.2	10.1	0.1	19.3
L-2	5.0	14.8	0.0	19.8	7.9	11.4	0.0	19.3
L-3	4.9	14.4	0.0	19.3	8.0	11.5	0.0	19.5
M-1	6.0	12.0	0.1	18.0	9.1	10.0	0.1	19.1
M-2	5.8	13.4	0.0	19.2	9.1	10.3	0.1	19.4
M-3	5.7	14.2	0.1	19.9	9.1	7.4	0.0	16.5
R-1	6.2	13.6	0.1	19.8	10.4	8.9	0.1	19.3
R-2	5.9	14.0	0.0	19.9	9.3	10.2	0.1	19.5
R-3	5.7	14.2	0.1	19.9	9.0	10.6	0.1	19.6
Average	5.7	13.8	0.0	19.5	9.1	10.1	0.1	19.2
Maximum variation	4.9 to 6.2	.....	.....	.....	7.9 to 10.3	.....	.....	.....
(b)	5.9	14.0	0.1	19.9	9.1	10.3	0.1	19.4

Sample.[a]	Set 3.				Set 4.			
	CO_2.	O_2.	CO.	$CO_2 + O_2 + \frac{1}{2}CO$.	CO_2.	O_2.	CO.	$CO_2 + O_2 + \frac{1}{2}CO$.
L-1	10.5	8.8	0.3	19.4	11.8	7.2	0.2	19.1
L-2	8.6	10.6	0.4	19.4	10.8	8.3	0.1	19.1
L-3	9.3	10.0	0.1	19.3	11.1	8.0	0.1	19.1
M-1	10.8	8.3	0.0	19.1	11.0	6.3	0.0	17.3
M-2	10.2	9.0	0.0	19.2	11.8	7.2	0.2	19.1
M-3	10.2	6.8	0.0	17.0	12.0	5.4	0.0	17.4
R-1	11.0	7.9	0.1	18.9	12.6	6.2	0.0	18.8
R-2	10.4	8.9	0.0	19.3	11.9	7.0	0.1	18.9
R-3	10.0	9.2	0.1	19.2	11.8	7.1	0.1	18.9
Average	10.1	8.8	0.1	18.9	11.6	7.0	0.1	18.6
Maximum variation	8.6 to 11.0	.....	.....	.....	10.8 to 12.6	.....	.....	.....
(b)	10.3	9.1	0.1	19.4	11.8	7.4	0.2	19.3

[a] See figure 33. [b] Sample taken through 1¼-inch perforated pipe.

The preceding analyses of gas samples show that the gases in the uptake of a water-tube boiler form a fairly homogeneous mixture. This uniformity of mixture is ascribed to the fact that the gases mix freely as they pass among the tubes. In any fire-tube boiler no such mixing can occur; the gases in each tube stay separate as long as they stay in the tubes. Therefore, it would seem that the gases in the uptake of a horizontal tubular boiler would not be a uniform mixture, but that their composition would vary considerably in different parts of the uptake. To determine how much this variation is, a set of nine open-end sampling tubes was placed in the uptake of a 100-horsepower horizontal tubular boiler and several sets of simultaneous samples were collected and analyzed. The placing of the sampling tubes in the uptake is shown in figure 34.

The tubes were connected to the gas-collecting apparatus shown in figure 32. The sample from each tube was collected over mercury in a separate gas holder. The time of collecting the gas sample was

about two minutes. Table 4 gives the analyses of the first four sets of samples. No sample was collected with a perforated-tube sampler. The analyses show that the composition varies over a wide range, and that the central sample as a rule contains a higher percentage of CO_2 than the average of the nine tubes.

Table 5 gives the analyses of four more sets of samples collected at various intervals after four equal and consecutive firings. Simultaneous samples were also collected with a perforated-tube sampler placed near the intakes of the nine open-end sampling tubes as shown in figure 34. The sample collected through the perforated sampler was nearer to the average than the sample taken with the center open-end tube; however, the difference was by no means small or negligible. The variation of the composition of the samples shows rather emphatically that it is very difficult, if not impossible, to collect a sample of flue gas that will represent the average composition of gases at a given cross section in the uptake of a horizontal return-tubular boiler.

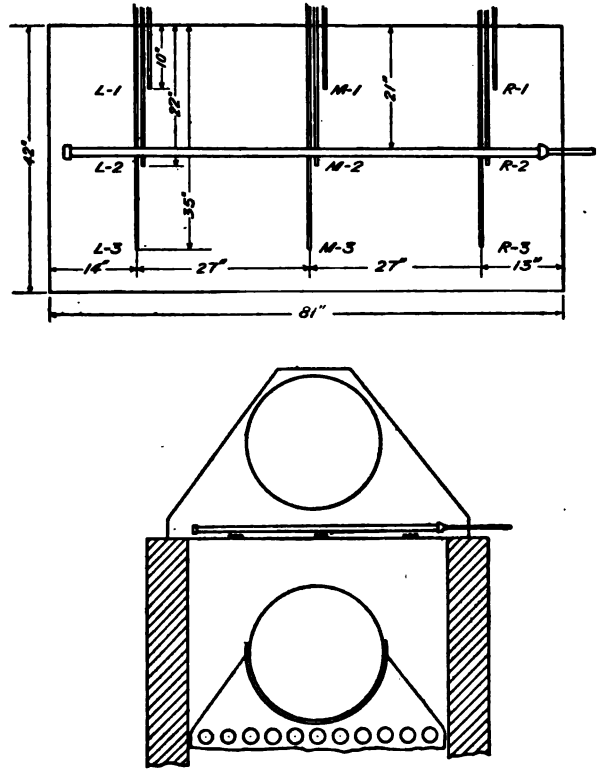


FIGURE 33.—Placing of nine open-end sampling tubes and a perforated-pipe sampler in a Heine boiler equipped with Jones stoker.

In general, it may be stated that flue or furnace gas samples as they are ordinarily taken do not represent the average composition of the entire stream of gas nearer than 0.5 per cent of CO_2, and in many instances the sample collected is 1 per cent or more of CO_2 higher or lower than the true average. It is therefore useless to make the analyses any closer than to the nearest 0.5 per cent of CO_2, particularly if no determination of the combustible gases is made.

TABLE 4.—*Results of analyses of samples collected in uptake of horizontal return-tubular boiler.*

Sample No.[a]	Set 1.			Set 2.				
	CO_2.	O_2.	CO_2+ O_2+ ½CO.	CO_2.	O_2.	CO.	H_2.	CO_2+ O_2+ ½CO.
1	10.1	8.6	18.7	12.1	7.3	.....	.....	19.4
2	12.4	6.5	18.9	14.8	4.0	.....	.....	18.8
3	12.2	6.8	19.0	15.3	3.3	.....	.....	18.6
4	12.9	5.3	18.2	16.0	2.6	0.8	0.0	19.0
5	13.2	5.8	19.0	15.0	3.4	1.0	0.2	18.9
6	9.0	10.3	19.3	13.4	5.4	0.5	0.4	19.0
7	8.6	10.7	19.3	11.8	7.4	.....	.....	19.2
8	8.3	11.2	19.5	12.7	6.5	.....	.....	19.2
9	9.0	10.3	19.3	13.4	4.4	.....	.....	17.8
Average	10.6	8.4	19.0	13.8	4.9	.....	.....	18.7
Maximum variation	8.3 to 13.2	.....	.....	11.8 to 16.0	.....	.....	.....	.....

Sample No.[a]	Set 3.						Set 4.			
	CO_2.	O_2.	CO.	H_2.	CH_4.	CO_2+ O_2+ ½CO.	CO_2.	O_2.	CO.	CO_2+ O_2+ ½CO.
1	9.0	7.3	5.5	2.3	0.4	19.1	12.8	7.2	0.1	20.0
2	10.7	4.9	6.6	3.1	.3	18.9	15.2	4.2	0.0	19.4
3	12.0	3.5	5.9	2.7	.4	18.5	15.7	4.6	0.0	20.3
4	12.5	2.7	5.9	2.6	.3	18.2	14.2	5.7	0.0	19.9
5	11.9	4.4	3.7	1.7	.1	18.2	12.7	7.0	0.0	19.7
6	10.3	7.2	2.8	1.3	.1	18.9	11.8	8.1	0.0	19.9
7	10.2	7.4	2.8	1.0	.3	19.0	10.7	9.8	0.0	20.5
8	10.1	7.4	2.7	.7	.4	18.9	10.8	9.2	0.0	20.0
9	11.5	6.2	1.9	.9	.3	18.7	10.2	9.3	0.1	19.5
Average	10.9	5.7	4.2	1.8	.3	18.7	12.7	7.2	.....	19.9
Maximum variation	9.0 to 12.5	.....	.....	.....	.....	.....	10.2 to 15.7	.....	.....	.....

[a] See figure 34.

TABLE 5.—*Results of analyses of samples collected in uptake of horizontal return-tubular boiler at various intervals after firing.*

Sample No.[a]	Immediately after firing.						1½ minutes after firing.					
	CO_2.	O_2.	CO.	CH_4.	H_2.	CO+CH_4+H_2.	CO_2.	O_2.	CO.	CH_4.	H_2.	CO+CH_4+H_2.
1[b]	0.0	20.0	.....	.....	.....	.....	8.3	10.1	1.1	0.0	0.5	1.6
2	9.8	7.4	2.5	0.5	1.1	4.1	10.2	7.7	1.5	.0	1.2	2.7
3	9.8	7.4	2.5	.5	1.2	4.2	11.9	5.5	1.7	.2	.4	2.3
4	10.4	6.4	2.8	.7	1.3	4.8	12.3	5.1	1.7	.2	.5	2.4
5	9.8	7.2	2.7	.7	1.4	4.8	11.2	6.2	2.0	.3	.7	3.0
6	10.0	6.8	2.9	.8	1.8	5.5	11.2	6.0	2.2	.3	.9	3.4
7	8.6	8.4	2.9	.5	.9	4.3	8.9	8.8	1.9	.3	.9	3.1
8	7.4	10.0	2.2	.2	1.7	4.1	8.7	9.2	2.0	.4	.6	3.0
9	7.1	9.3	2.4	.4	1.4	4.2	8.4	9.2	2.0	.5	.4	2.9
Average	9.1	7.9	2.6	.5	1.4	4.5	10.1	7.5	1.8	.2	.7	2.7
Maximum variation	7.1 to 10.4	.....	.....	.....	.....	.....	8.3 to 12.3	.....	.....	.....	.....	.....
(c)	9.5	7.5	2.3	.4	1.5	4.2	10.4	6.7	1.5	.1	.5	2.1

[a] See figure 34. [b] Air leak. [c] Sample taken through 1-inch perforated pipe.

TABLE 5.—*Results of analyses of samples collected in uptake of horizontal return-tubular boiler at various intervals after firing*—Continued.

Sample.[a]	2½ minutes after firing.						3½ minutes after firing.					
	CO_2.	O_2.	CO.	CH_4.	H_2.	$CO+CH_4+H_2$.	CO_2.	O_2.	CO.	CH_4.	H_2.	$CO+CH_4+H_2$.
1[b]	9.2	9.6	0.4	0.0	0.0	0.4	9.5	8.6	0.8	0.0	0.2	1.0
2	11.7	6.5	.5	.0	.0	.5	11.2	6.4	.9	.0	.4	1.3
3	12.4	5.7	.2	.0	.0	.2	12.5	5.1	.9	.0	.4	1.3
4	12.8	5.5	.2	.0	.0	.2	12.4	4.6	1.5	.....	.....	.....
5	11.7	5.9	.7	.0	.1	.8	11.7	5.8	1.0	.0	.1	1.1
6	11.0	6.4	.7	.0	.4	1.1	11.5	6.3	.8	.0	.1	.9
7	9.7	7.1	1.6	.1	.6	2.3	10.7	7.5	.4	.0	.1	.5
8	9.0	9.5	.6	.0	.2	.8	8.4	10.3	.2	.0	.1	.3
9	9.8	7.8	1.1	.0	.0	1.1	8.9	9.7	.3	.0	.1	.4
Average	10.8	7.1	.7	.....	.1	.8	10.8	7.1	.8	.0	.2	1.0
Maximum variation	9.0 to 12.8	.....	.....	.....	.....	.....	8.4 to 12.5	.....	.....	.....	.....	.....
(c)	11.4	6.8	.2	.0	.1	.3	12.3	5.3	.9	.0	.4	1.3

[a] See figure 34. [b] Air leak. [c] Sample taken through 1-inch perforated pipe.

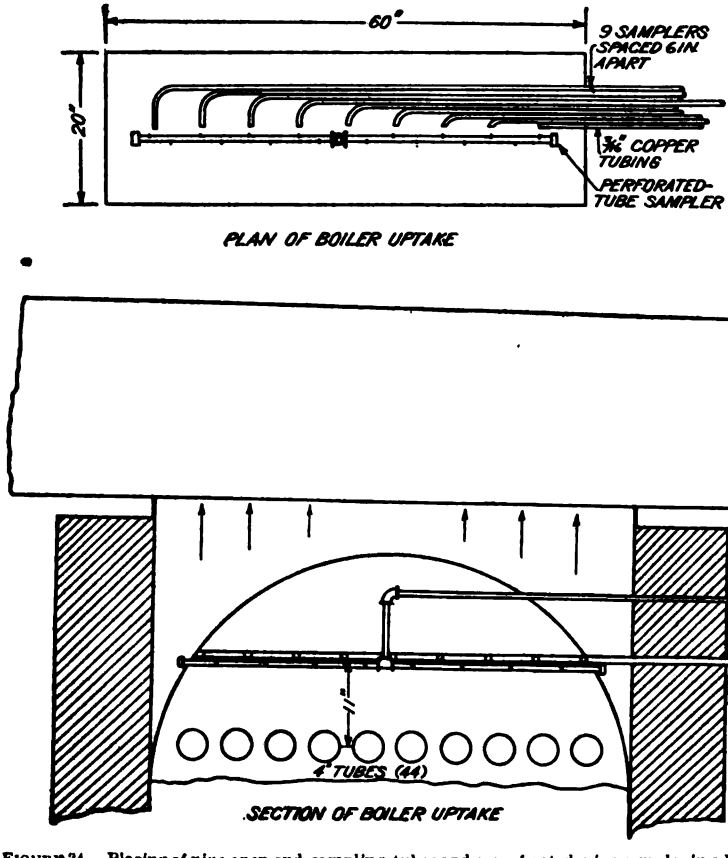


FIGURE 34.—Placing of nine open-end sampling tubes and a perforated pipe sampler in a horizontal return tubular boiler. The open-end tubes are of $\frac{3}{16}$-inch copper tubing.

EXPERIMENTS ON COLLECTING GASES.

In sampling flue gases it is desirable to collect the sample at a uniform rate for a period ranging from 15 minutes to several hours. The longer this period the more difficult it is to obtain a uniform rate of collecting gases with the ordinary 2-gallon collecting bottles. The main difficulty in collecting gas over long periods is that the water must be run out of the bottle through a very small opening which is apt to become stopped with small particles of dirt floating in the water. When the small opening is made by pinching the rubber tubing by the screw clamp shown in figure 9, the opening has a shape of a long and narrow slit which acts as a filter and catches all the dirt and becomes stopped. Better results can be obtained by using a small orifice like that shown in figure 35.

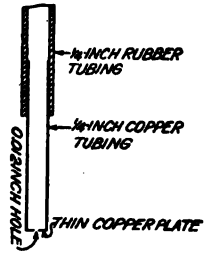


FIGURE 35.—Orifice used to obtain a uniform flow of water. The copper tube is inserted into the rubber tubing which discharges water into lower collecting bottle.

The orifice has a round opening which does not clog as easily as the long narrow slit formed by compressing the rubber tubing with the screw clamp. When collecting gas samples over long periods it is important that the water or brine used be free from all dirt. Filtering the brine or water through filter or blotter paper reduces the trouble from clogging.

Numerous experiments were made in the gas laboratory of the Bureau of Mines to determine how uniform a rate of collecting the gas may be expected when the sampling is extended over periods of 1 to 5 hours. Some of the results obtained are plotted in figure 36.

The horizontal distance of the chart gives the time over which the gas was collected. The vertical distance of the lower curves gives the volume of gas collected in a given period, each curve giving the volume with one adjustment of the screw clamp or an orifice. The vertical distance of the upper curves is the effective head in inches of water, this effective head decreasing as the water runs out of the bottle. The decrease in head gives a slight curvature to the lower curves, showing that the rate of collecting the gas is not quite uniform. It will be noticed that the curves obtained with the orifice are nearer a straight line than those obtained with the screw clamp. Curve 2 is a typical curve showing the results of dirt accumulating in the narrow slit in the rubber tubing and gradually stopping the flow of water. When the gas is collected over a period of 5 hours the water flows out of the collecting bottle at the rate of about two drops per second.

If the collection is started with an effective head smaller than those shown in figure 36, the rate of collection will not be as uniform as shown by the curve in the figure.

EXPERIMENTAL DATA ON THE ABSORPTION OF CO_2 BY WATER AND BRINE.

Gases are absorbed by liquids from a mixture of gases according to their partial perssures. The amount depends upon the nature

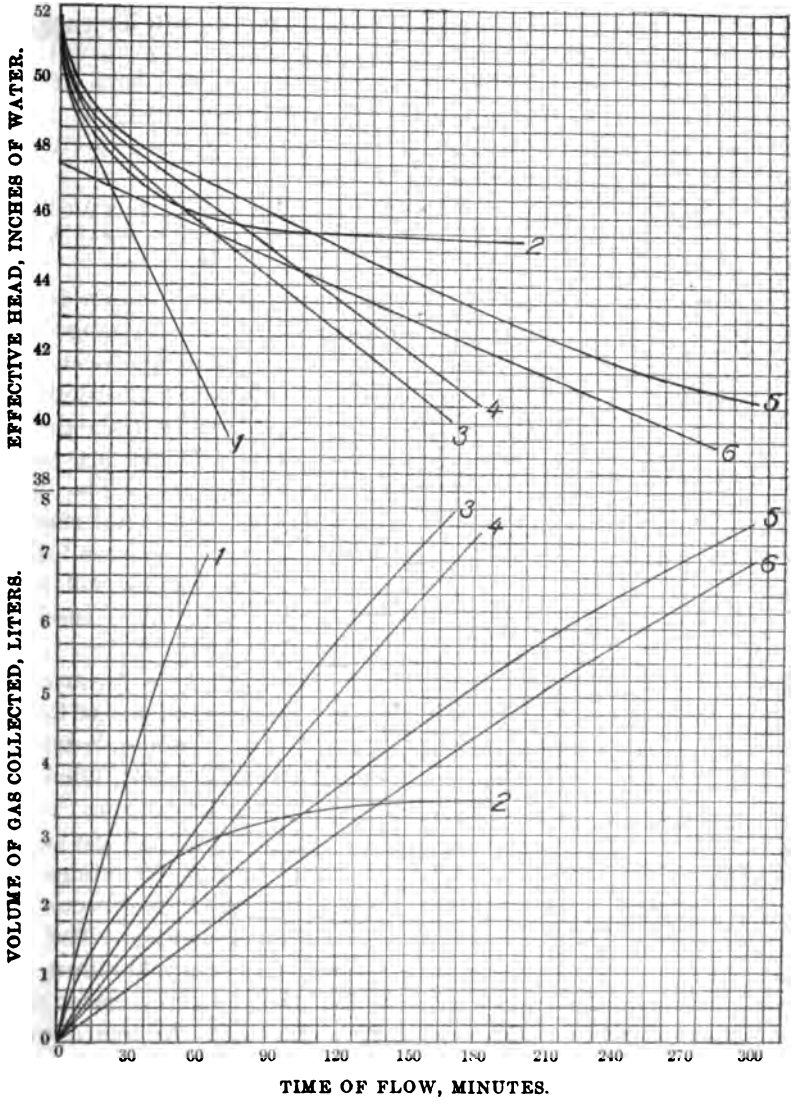


FIGURE 36.—Curves showing the uniformity of rate of collecting gas with two collecting bottles arranged as shown in figure 8. Upper curves show the change in effective head, lower curves the volume of gas collected. Curves 4 and 6 were obtained with orifice; all others with screw clamp.

of the substances and the temperature. Solids dissolved in liquids decrease the solubility of gases in the liquids, if there is no chemical action.

When flue-gas samples are being collected, the solubility of CO_2 in the liquid over which the gas is collected changes when the composition of the flue gas changes. If the liquid has been saturated with flue gas containing 10 per cent of CO_2, and a gas containing 4 per cent of CO_2 is collected over the liquid, CO_2 will pass from the liquid into the gas, and the percentage of CO_2 in the gas will increase. In a similar manner, if gas containing 10 per cent of CO_2 is collected over a liquid in equilibrium with 4 per cent of CO_2, some CO_2 will pass from the gas to the liquid and the percentage of CO_2 in the gas will decrease. These facts are shown clearly by the experimental results given in Tables 6 to 10.

The experiments were made to determine the extent to which these changes take place when water or a salt solution is used for the confining liquid.

The tests were all made under similar conditions, the same relative quantities of gas and liquid being used in each test. A change in the quantity of either will change the results, especially if the gas and the liquid are shaken together. The larger the contact surface between gas and liquid the greater will be the speed of interchange of CO_2.

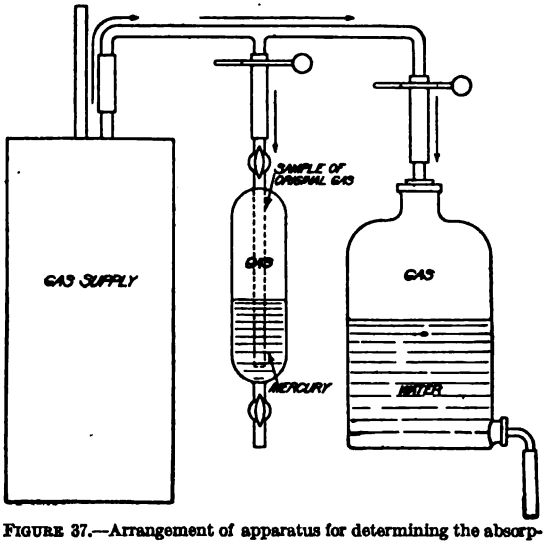


FIGURE 37.—Arrangement of apparatus for determining the absorption of CO_2 when collecting the gas over water or brine.

The experiments were made as follows: A 2-gallon bottle was completely filled with water or brine. About 1 liter of gas with a given percentage of CO_2 was then collected over the water. The water and the gas were shaken 5 minutes, then left to stand 30 minutes and again shaken for 5 minutes. With this procedure the water or the brine was brought nearly into equilibrium with the gas above it. A sample of the gas was analyzed for CO_2, and the figures obtained are the values given in the first column of the tables. The water or brine thus prepared was used in collecting a sample of gas containing either a lower or a higher percentage of CO_2 than the gas with which the liquid was previously in contact. As the gas was collected in the bottle a small part of the gas stream was led into a small gas container and collected over mercury. The arrangement of apparatus for the collection of these samples is shown in figure 37.

The collecting bottle was filled about two-thirds with gas and left standing undisturbed. The gas collected in the small gas container was of the same composition as the gas flowing into the large collecting bottle, and its composition was not affected by the mercury. Therefore its analysis gave the percentage of CO_2 in the gas as it flowed into the collecting bottle. In Tables 6, 8, and 10 this percentage is given in the third column, and in Tables 7 and 9, in the second column.

After each of 2, 4, and 21 hour periods a small gas sample was taken out of the large collecting bottle and analyzed. The percentages of CO_2 found by the analyses are given in Tables 6 to 10. In some experiments the temperature of the water in the collecting bottle was measured at the time a sample was taken for analysis. These temperature readings are given alongside the CO_2 percentages.

In some of the experiments after the gas and liquid had stood 21 hours and the percentage of CO_2 in the gas had been determined, the gas and liquid were shaken together for five minutes and the gas was again analyzed for CO_2. The results of such determinations of CO_2 are given in the second column of Tables 6 and 8.

The experiments were made with water with a 10 per cent brine solution and with saturated, or about 35 per cent, brine. The 10 per cent brine solution was prepared by dissolving 1 pound of common salt in 9 pounds of water. The saturated, or about 35 per cent, brine was obtained by dissolving all the salt that would go into solution—about 3½ pounds of salt per 10 pounds of water.

Table 9 gives the data on the absorption of CO_2 when the gas was bubbled through the liquid, with a constant effective head, as shown in figure 10. The duration of bubbling the gas through the liquid is given by the last column of the table.

Table 10 gives the data from experiments made to determine the effect of shaking the gas and water or brine together. Gas of given composition was collected over the liquid in a bottle, the collection lasting about five minutes. One sample was taken and analyzed immediately after collection. The bottle was then shaken for five minutes and the sample again analyzed for CO_2.

In all the experiments the same quantity of gas and liquid was used; that is, two-thirds of the volume of the bottle was gas and one-third was water.

TABLE 6.—*Data showing the tendency of water to absorb and give out CO_2.*

Percentage of CO_2 in gas after contact with water.	Temperature of water.	Percentage of CO_2 in original gas.	Percentage of CO_2 in gas after standing over water for—						Percentage of CO_2 in gas after standing 21 hours and being shaken 5 minutes.	Temperature of water when gas was analyzed.[b]
			Two hours.	Temperature of water.[a]	Four hours.	Temperature of water.[a]	Twenty-one hours.	Temperature of water.[a]		
	°C.			°C.		°C.		°C.		°C.
5.0	.....	8.9	8.8	.....	8.6	.....	7.9	.....	.....	.....
5.0	.....	11.6	11.3	.....	11.0	.....	9.2	.....	.....	.....
8.0	.....	11.9	11.7	.....	11.8	.....	10.9	.....	.....	.....
4.0	.....	15.0	[b] 14.9	.....	13.6	.....	10.5	.....	.....	.....
7.7	.....	4.4	4.6	.....	4.8	.....	5.4	.....	.....	.....
17.0	.....	2.7	3.1	.....	3.5	.....	6.3	.....	.....	.....
4.5	21	10.3	10.1	22	9.9	23	8.8	22	8.0	22
4.6	29	10.8	10.8	30	10.1	32	9.3	27	8.6	27
5.0	23	13.0	12.9	24	12.6	25	10.6	20	9.2	20
6.6	27	8.8	8.7	29	8.5	29	7.9	27	7.9	27
10.1	28	3.9	4.2	30	4.4	31	5.2	22	5.9	22
12.0	24	5.6	5.7	24	5.9	25	6.7	26	8.3	26

[a] Temperature was recorded only where given in the table.
[b] Gas had stood over water only one hour.

TABLE 7.—*Data showing the tendency of 10 per cent brine to absorb and give out CO_2.*

Percentage of CO_2 in gas after contact with 10 per cent brine.	Percentage of CO_2 in original gas.	Percentage of CO_2 in gas after standing over 10 per cent brine for—		
		Two hours.	Four hours.	Twenty-one hours.
3.9	8.9	8.9	9.0	8.2
4.0	15.0	[a] 15.0	14.5	12.7
5.0	11.6	11.5	11.5	10.2
8.0	11.9	11.8	11.6	11.0
10.6	4.4	4.5	4.6	6.7
17.0	2.7	2.7	3.1	4.9

[a] Gas had stood over brine only one hour.

TABLE 8.—*Data showing the tendency of saturated brine to absorb and give out CO_2.*

Percentage of CO_2 in gas after contact with saturated brine.	Temperature of water.	Percentage of CO_2 in original gas.	Percentage of CO_2 in gas after standing over saturated brine for—						Percentage of CO_2 in gas after standing 21 hours over brine and then shaking for 5 minutes.	Temperature of water.
			Two hours.	Temperature of water.	Four hours.	Temperature of water.	Twenty-one hours.	Temperature of water.		
	°C.			°C.		°C.		°C.		°C.
2.5	21	10.3	10.3	22	10.2	23	9.7	22	8.1	22
5.5	23	13.0	13.1	24	13.0	25	12.0	20	11.3	20
10.4	28	3.9	4.0	30	4.1	31	4.4	22	4.5	22
12.0	24	5.6	5.8	24	5.6	25	5.9	26	6.5	26

TABLE 9.—*Data showing the effect of bubbling gas through water and brine with a constant head.*[a]

Percentage of CO_2 in gas after contact with brine.	Percentage of CO_2 in original gas.	Percentage of CO_2 after bubbling through water.	Percentage of CO_2 after bubbling through 10 per cent brine.	Time of collecting.
				Hours.
0.0	8.3	4.4	5.3	3½
4.5	13.2	7.6	8.3	3½
16.5	10.6	12.8	12.6	4
9.7	6.0	7.5	6.0	1

[a] See fig. 10 (p. 17).

TABLE 10.—*Data showing effect of shaking gas and water, or 35 per cent brine, in collecting bottle.*

Liquid shaken with gas.	Percentage of CO_2 in gas after contact with liquid.	Percentage of CO_2 in original gas.	Percentage of CO_2 after shaking gas and liquid five minutes.
Water	12.0	6.3	7.5
	7.4	11.7	10.8
	3.9	18.5	14.8
Saturated brine	11.9	6.2	7.3
	7.4	11.7	11.0
	3.9	18.5	16.7

CONCLUSIONS FROM EXPERIMENTS ON ABSORPTION OF CO_2 BY LIQUIDS.

The results of the experiments just described permit the following conclusion: With greatly varying compositions of flue gas the error resulting from absorption or giving out of CO_2 by the confining liquid may amount to 3 or 4 per cent of CO_2. The error is less with 10 per cent brine than with water and less with saturated brine than with 10 per cent brine.

Shaking the gas and the liquid together increases the absorption or giving out of CO_2 by the liquid.

The largest error is introduced when the gas is bubbled through water. Therefore this method of collecting gas should not be used.

If the percentage of CO_2 does not vary more than 2 or 3 per cent and if the gas does not stand over the liquid more than 2 hours, water may be used satisfactorily for the confining liquid. If, however, the variation of CO_2 exceeds 3 per cent and the gas stands over the liquid a long time, brine can be used to good advantage. The brine is not as convenient to handle as pure water; the water evaporates and the salt is deposited on all surfaces and mars the appearance of the apparatus.

Gas should be analyzed as soon as collected; shaking of the liquid and any change in its temperature should be avoided.

Ordinarily when collecting flue gases in the boiler room it is doubtful whether the percentage of CO_2 of the collected gas when analyzed is closer than 0.5 per cent of the gas as it enters the collecting bottle.

Considering all the possible errors that may and often do enter into the sampling and collecting of flue gas, one is justified in looking with suspicion on many of the published heat balances of boiler trials. The possible errors make the determination of radiation losses by difference in the heat balance questionable.

PUBLICATIONS ON FUEL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and applicants should limit their selecting to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl., 9 figs.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl., 7 figs.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls., 7 figs.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. J. Groves, and K. M. Way. 1910. 62 pp., 1 fig.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls., 12 figs.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp., 1 pl., 16 figs.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls., 250 figs.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls., 4 figs.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 18. The transmission of heat into steam boilers, by Henry Kreisinger and W. T. Ray. 1912. 180 pp., 78 figs.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls., 94 figs.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp., 1 fig. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls., 2 figs. Reprint of United States Geological Survey Bulletin 366.

BULLETIN 28. Experimental work conducted in the chemical laboratory of the United States fuel-tesing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 51 pp. Reprint of United States Geological Survey Bulletin 323.

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Bulletin 98

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

Page.
I

REPORT

OF THE

SELBY SMELTER COMMISSION

BY

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AND

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WITH ACCOMPANYING PAPERS

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PREFACE.

Smelter-smoke problems were among the first to receive attention by the Bureau of Mines in its endeavors to increase efficiency and lessen or prevent waste in the utilization of the mineral resources in the United States. The problems presented to the bureau included the determination of the actual economic waste involved in the escape of dust, fume, and gas from the stacks of metallurgical plants, more especially those treating sulphide ores, as well as the damage to plants and animals and the creation of a public nuisance.

The work undertaken by the bureau involved the examination of conditions in the vicinity of smelting plants and the methods adopted or on trial to prevent the loss of valuable substances in smelter smoke and to prevent damage by the constituent fumes and gases; the determination of new uses or wider uses for those constituents wasted from lack of a market or inability to recover them at a profit by existing methods; and also the laboratory study of the fundamental physical and chemical reactions of those metallurgical processes that cause smoke and fume.

As in its investigations relating to methods of increasing safety and health conditions in mines, so in its metallurgical investigations the Bureau of Mines endeavors to cooperate actively, so far as it can under the terms of its organic act, with Government and State bodies and with private organizations that are endeavoring to bring about such improvements in industrial methods and conditions as come within the scope of the bureau's purpose. Although the bureau is forbidden by law to make reports on mineral properties for private individuals, its engineers and chemists, as expert advisers for the Government, have done much work dealing with safety and efficiency in the development and utilization of the mineral resources of the country.

Moreover, the bureau has believed that much controversy and much needless and expensive litigation regarding damage to public interests by mines or by metallurgical plants can be avoided by the appointment of commissions composed of unbiased experts who, from their knowledge of the principles involved, will determine with precision the essential facts and their relation to matters in controversy and will lay down findings that, because of the manner in which they had been formulated, will be accepted as final by the parties at interest. Absolute freedom of judgment is necessary for the success of such a commission. Expert testimony produced by

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either litigant is under suspicion by the other, but scientific and technical investigations by the Federal Government or by an unbiased commission inspire confidence, and findings based on such investigations command respect.

For these reasons when, as a result of protracted litigation between the Selby Smelting & Lead Co. and the citizens of Solano County, Cal., it was decided to refer to a commission the question whether the Selby company was violating the terms of a court injunction, the Director of the Bureau of Mines, under instructions from the Secretary of the Interior, accepted the chairmanship of this commission, and various chemists and other employees of the bureau who had been or were engaged in work relating to smelter smoke were authorized to facilitate the work of the commission by carrying on incidental investigations. Under this arrangement the commission benefited by the work of skilled experts, and the Government employees gained valuable knowledge and experience without the Government being subject to any additional expenditure.

This bulletin presents the report of the commission and the papers, prepared by the various experts, which give the results of investigations undertaken by the commission and form the basis of its findings. The papers include detailed discussions of the effect of smelter smoke on vegetation, by A. E. Wells, J. W. Blankinship, and W. W. Jones, and on horses, by C. M. Haring and K. F. Meyer, and a review of local opinions, by C. B. Dutton. These papers are published essentially as presented to the parties at issue—the smelting company and the county officials—except that, in editing, certain changes of style have been made in compliance with the Government regulations and certain statements dealing with persons who were examined have been modified or stricken out, the purpose being to present all essential facts relating to the questions submitted to the commission and to omit such opinions as did not rest on provable statements.

As here assembled, the report of the Selby Commission is published by the Bureau of Mines as a contribution to the literature of metallurgical smoke in its relation to plant growth and to public health and comfort, and as an example of what is believed to be a satisfactory method of dealing with legal controversies over the damage inflicted by mining and metallurgical establishments.

J. A. Holmes.

REPORT OF THE SELBY SMELTER COMMISSION.

FORMAL PRELIMINARY STATEMENT OF THE MEMBERS OF THE COMMISSION.

The People of the State of California, Selby Smelting & Lead Co. (a corporation), *ss:*

GREETINGS.

The Selby Smelter Commission has the honor to submit, herewith, its conclusions, findings, and recommendations as provided for in the stipulation filed in connection with the decree of the superior court of Solano County, Cal., dated July 16, 1908, entitled:

The People of the State of California, *Plaintiffs*,
v.
Selby Smelting & Lead Co. (a corporation), *Defendant.* } No. 2980.

The commission may be permitted to express its earnest hope that the litigation which comes to an end with the findings and recommendations herein set forth will be considered by both parties to the action as definitely and equitably decided.

The commission trusts that its work will show the value of the commission form of settlement and that its work will serve as a precedent to be followed in disputes relative to technical subjects. If the work of the commission is productive of a tendency on the part of technical litigants to avoid the use of the courts for the settlement of disputes it will not have been done in vain. Such tendency will surely grow and ultimately such differences will be arbitrated by technically trained men without recourse to the courts of law.

Appended to the report of the findings of the commission are to be found the detailed reports covering the several lines of inquiry and investigation carried on by the commission and upon which its findings are based, and also a detailed statement of the fiscal affairs of the commission. A word of explanation is necessary in regard to the fiscal statement. While each party to the litigation has agreed to bear one-half of the expense of the investigations of the commission, it will be noted that the Selby Smelting & Lead Co. is credited with $21,000, while Solano County is credited with but $6,000. In order that the investigations of the commission might go forward without interruption the Selby Smelting & Lead Co. has generously supplied funds at the times they were needed. This assistance has been

accepted by the commission in the full belief that Solano County, in accordance with its agreement, would reimburse the Selby Smelting & Lead Co., through the commission, by appropriating funds at the earliest possible moment to meet its obligations in this connection.

Respectfully,

(Signed) J. A. HOLMES.
EDWARD C. FRANKLIN,
RALPH A. GOULD.

FORT BAYARD, N. MEX.,
November 5, 1914.

ORIGIN, PURPOSE, AND PERSONNEL OF THE COMMISSION.

The Selby Smelter Commission is a body organized for the determination of questions of fact and other matters concerned with certian injunction proceedings at issue between the people of the State of California and the Selby Smelting & Lead Co. Authority for the organization of the commission is found in a stipulation filed in the superior court of Solano County, Cal., as a portion of the record of the case.

THE INJUNCTION DECREE.

On March 14, 1905, the district attorney of Solano County, acting upon complaints which had been made by the residents of the city of Benicia and its tributary country, all of which area is located within the boundaries of Solano County, brought an action in the superior court of Solano County praying for an injunction which would restrain and enjoin the Selby Smelting & Lead Co. from permitting the smoke from the Selby smelter to blow over and upon the territory above mentioned. The offending smelter is situated near Vallejo Junction, Contra Costa County, Cal., about 5 miles directly west of the city of Benicia and about 1 mile directly south of the nearest point of land included in the area in which the complaints arose.

On October 23, 1905, the Selby Smelting & Lead Co. entered a demurrer to the complaint. The demurrer was overruled by the court on February 6, 1906. Answer to the complaint was thereupon filed by the company on May 19, 1906, and on August 7, 1906, the case was brought to trial before the court, jury having been waived by both parties to the suit. The case was lengthy and involved the taking of much testimony, both lay and expert, so that the court's opinion was not filed until late in October, 1906, and it was not until April 22, 1907, that the findings of fact and conclusions of law were filed by the court. On July 16, 1908, judgment was rendered in favor of the plaintiff. The judgment of the court follows:

IN THE SUPERIOR COURT OF THE COUNTY OF SOLANO, STATE OF CALIFORNIA.

The People of the State of California, *Plaintiffs*,
v.
Selby Smelting & Lead Co. (a corporation), *Defendant*. } No. 2980.

JUDGMENT.

This cause came on regularly for trial, the parties appearing by their attorneys. A trial by jury having been expressly waived by counsel for the respective parties, the cause was tried before the court, whereupon testimony, documentary and oral, on the part of plaintiff and defendant, was introduced; the evidence being closed, the cause was submitted to the court for consideration and decision, and after due deliberation thereon the court delivers its findings and decision in writing, which are filed, and orders that judgment be, and be entered in accordance therewith.

Wherefore, by virtue of the law and the findings aforesaid, it is ordered, adjudged, and decreed that the operation at its works, for the reduction of ores, upon the Straits of Carquinez, near Vallejo Junction, in the County of Contra Costa, in said State of California, as conducted by defendant in liberating at and therefrom into the air sulphurous and other injurious and noxious gases and smoke, and also smoke and fumes and gases, so in the findings of fact herein to be offensive to the senses so as to interfere with the comfortable enjoyment of life and property in the manner, and to the community and neighborhood, as in the said findings of fact set forth and described, generated or produced by such operations without condensing or otherwise disposing of the same or eliminating the same before reaching the open air, is as to said city of Benicia and said portion of said Solano County mentioned and referred to in said findings, a public nuisance for the period commencing at or about the middle of the month of March of each year, for eight months in each and every year, including the latter half of said month of March.

It is further ordered, adjudged, and decreed that said nuisance be abated by said defendant, and that defendant and its officers, agents, servants, and employees, and each and all of them, are hereby perpetually enjoined and restrained from roasting, burning, smelting, refining, or treating any ores, or their products, at or by or in the operation of said works, for and during the period in each year commencing at or about the middle of the month of March in each year until the middle of November in each year, including the latter half of said month of March, during which period said nuisance exists, without condensing or otherwise disposing of or eliminating, before reaching the open air, all said sulphurous and other noxious and injurious gases and smoke, and also said smoke, fumes, and gases so found to be offensive to the senses, generated or produced by said works, or the operation thereof, and in such manner so that the same will not reach the open air and will not be blown or carried by said winds over or into or upon the city of Benicia and that portion of Solano County beginning at said city of Benicia and running in a westerly direction to a point in said Solano County situated upon the Straits of Carquinez where the Napa River flows into said Straits of Carquinez.

Dated this 14th day of July, 1908.

L. G. HARRIER,
Judge of said Superior Court.

Entered this 16th day of July, 1908.

G. G. HALLIDAY, *County Clerk.*

On July 25, 1908, the defendant company gave notice of intention to move for a new trial. Motion for new trial of the cause was denied by the court on November 22, 1909, and on December 2, 1909, an

appeal was taken to the supreme court of the State from the order denying the motion for a new trial. On June 12, 1912, the judgment of the trial court was affirmed by the supreme court of the State.

CREATION OF THE COMMISSION.

During the period of time covered by the numerous steps of the legal proceedings much complaint was made by residents of the area referred to, and after the judgment was pronounced numerous and emphatic complaints from the citizens of the territory were made to the effect that the injunction was being violated.

The Selby Smelting & Lead Co. in the meantime had made very considerable and commendable progress towards abating such objectionable smoke as they discharged into the air at the time of the trial. During the spring of 1913 complaints were again made that the nuisance existed. The company maintained that they had abated the nuisance. In order to avoid the expenses to both parties to the litigation attendant upon a trial of the smelter company for contempt of court, conferences of the attorneys representing both sides developed a desire to submit the question of fact as to the violation of the injunction to a board of technically trained men deemed by both sides to be qualified to act in such a capacity. The result of the conferences was the filing of a stipulation in the record of the action providing for such a board.

The stipulation was filed on March 16, 1913, and is as follows:

IN THE SUPERIOR COURT OF THE STATE OF CALIFORNIA IN AND FOR THE COUNTY OF SOLANO.

The People of the State of California, *Plaintiffs*, *v.* Selby Smelting & Lead Co. (a corporation), *Defendant.*	No. 2980.

STIPULATION.

Whereas, complaint has been made to the board of supervisors of the above-entitled county that the decree hereinbefore entered is being violated by the above-named defendant, and

Whereas, the above-named defendant claims and asserts that it is not violating the said decree but is operating its plant in all respects in accordance therewith, and is not doing any injury thereby, and

Whereas, the determination of the said question by the courts would involve a large expense and long delay in the determination of the quantity of deleterious and injurious fumes and gases, if any, emitted by the defendant, and would necessitate the taking of measurements and the collecting of a large amount of data, and

Whereas, in the opinion of both the parties hereto said question can be more easily investigated by a board of impartial experts qualified by their training and experience to consider questions of this nature.

Now therefore, for the purpose of facilitating the determinations of the truth as to the controversy above described, and to fix and determine the conditions under which the defendant's plant may operate,

It is hereby stipulated and agreed by the above-entitled parties that a commission consisting of J. A. Holmes, W. F. Snow, and Ralph A. Gould be, and they are hereby, agreed upon and appointed as a board of experts, which board shall, for such a period of time as may be required therefor not exceeding eight (8) months from the date hereof, investigate and report to the parties hereto concerning the operation of the defendant's plant with respect to the emission of deleterious or injurious fumes, if any, therefrom, and the effect, if any, thereof upon the territory alleged to be affected by the said plant in the county of Solano, including the city of Benicia, and also with respect to the methods, devices, or processes employed by the said defendant to reduce, minimize, or otherwise render less the said injurious fumes.

If the board shall find that the above-named defendant's contention is true and that it is not at the present time operating its plant in a manner to violate the decree heretofore duly given and made herein, it shall make a finding to that effect.

If the board shall find that the defendant is operating its plant in such manner as to produce smoke, fumes, and gases offensive to the senses, or destructive to the property of people residing in said district of Solano County, or so as in any manner to be violative of the said injunction, it shall make a finding to that effect. It shall also proceed to determine the specific amount of sulphurous or other fumes, smoke, or gas, if any, which the defendant may properly emit into the atmosphere without violating the terms and conditions of the said injunction, and shall also designate the means, apparatus, or process to be used and method of operation to be followed by the defendant in the operation of its plant, which in the opinion of the said commission is best calculated to carry out the tenor and effect of such determination. The apparatus to be used shall conform to the most approved, scientific, and practical process applicable to works of the character of said defendant, and the method of operation to be followed shall be such as to cause the necessary elimination or reduction in volume and character of the said fumes, smoke, and gases.

The defendant thereupon agrees not to emit into the atmosphere a greater amount of the specific fumes or gases than is permitted by the finding of said board, and agrees to use the means or method of operation and the apparatus designated by said board, or some other apparatus or method of operation which shall produce the same result so far as the specific amount of such noxious fumes or gases is concerned.

The said board may also from time to time during the said period make such inquiries, employ such experts, or otherwise fully advise itself of the conditions and matters under consideration.

The said board may from time to time during the said period make regulations as to the mode and method of operation of the plant of the said defendant and the amount of smoke, fumes, and gases to be emitted, which regulations shall and will be followed by the said defendant in the operation of such board as to the matters hereinbefore set forth.

The said parties agree that if at any time during the investigation and report upon operation of the said plant and the matters hereinbefore mentioned such board shall find as a fact that the operation of such plant is being conducted so as to be violative of the provisions of said injunction and to cause a public nuisance notice thereof may be given to the said parties hereto of such determination. Until such notice is given the operation of its works by the defendant, if in conformity to any regulations or directions of the said board, shall not be deemed to be violative of the said decree.

Pending such examination by said board defendant agrees to further increase the amount of material which is shipped elsewhere for roasting so that not to exceed 600 tons per month of sulphurets will be roasted instead of an amount of 2,400 tons, which formerly were handled monthly at said plant.

It is further agreed that the period of eight months hereinbefore referred to shall not be considered as part of the period during which the statute of limitations may

run as to any or all actions arising out of the operation of the defendant's works, whether for public or private nuisance or public or private injury or damage, and the said period of eight months shall be construed to be added to any period in determining when any existing cause of action may be barred by the running of the period of such statute.

It is further agreed that in event that either or any of the said persons appointed upon said board of arbitration are for any reason unable to act, or if after appointment they or either of them are unable to continue hereunder, that the attorneys for the plaintiff shall designate the persons who shall be substituted in his or their place.

By entering into this stipulation the defendant does not concede that it is causing to be emitted from its said works any deleterious or injurious fumes.

Dated March 15, A. D. 1913.

(Signed) T. T. C. GREGORY,
J. A. RAINES,
Attorneys for Plaintiffs.

(Signed) CHICKERING & GREGORY,
Attorneys for Defendant.

ORGANIZATION OF THE COMMISSION.

It developed after filing the stipulation that Dr. W. F. Snow was unable to serve upon the commission, and by mutual consent of the two parties to the action, through their attorneys, Edward C. Franklin was appointed as third member of the commission. Dr. Franklin was at that time director of the chemical laboratories of the United States Public Health Service in Washington, D. C., but later returned to his position as professor of organic chemistry at Leland Stanford Junior University. His acceptance of the appointment completed the full membership of the commission.

On May 22, 1913, the commission was formally organized as the Selby Smelter Commission, with the following personnel:

J. A. Holmes, Director of the United States Bureau of Mines, chairman of the commission.

Edward C. Franklin, professor of organic chemistry, Stanford University.

Ralph A. Gould, chemical engineer, San Francisco, secretary of the commission and in immediate charge of investigations.

In session the commission outlined its plan of study and investigation and began at once the active work of determining the questions involved in the stipulation and the injunction decree.

The active work of collecting data began about June 1, 1913, and was finished about September 1, 1914, a period of about 15 months. The tabulation, correlation, and study of the data has consumed the time from September 1 to the date of this report. Approximately $26,000 has been expended by the commission in the collection and presentation of the data. The commission has exerted its best endeavors to make this work both thorough and comprehensive.

SCOPE OF THE COMMISSION'S WORK.

The stipulation requires a report and finding by the commission on points which are summarized as follows:

1. Is the plant of the Selby Smelting & Lead Co. being operated in such a manner as to violate the decree of the court dated July 16, 1908?

2. If the defendant company is violating the decree, what is the extent of the violation?

3. If the defendant company is violating the decree, what remedial methods can be taken by the defendant to avoid a violation of the decree?

4. If the defendant company is not violating the decree, under what conditions must the plant operate so as not to violate the decree in the future?

The stipulation confers authority upon the commission to make such investigations as it may deem necessary for a just and equitable solution of the questions submitted, and gives the commission power to make recommendations, which are binding upon the defendant company for the future operation of the plant, with respect to the discharge of material into the atmosphere.

The commission entered upon its work with the distinct understanding of all parties concerned that the general good could be best conserved by a broad interpretation of the power delegated to the commission by the stipulation and the maintenance of a strictly neutral position and point of view. As contributing in no small degree to the establishment of the neutral position of the commission, should be mentioned the agreement of both parties to the legal proceedings to share equally in the cost of the investigation.

The members of the commission were actuated to serve in the belief that this method of settlement and the results obtained would serve as a precedent to contemplated future litigation concerning technical matters, and would mark a forward step in the elimination of costly and usually unsatisfactory court procedure.

THE COMMISSION'S STAFF.

The conduct of such a series of investigations as was desired required the services of a considerable number of trained scientific and technical men. In so far as it has been possible, each investigation has been carried out by the cooperation and collaboration of at least two specialists in that particular field. In some cases more than two men have collaborated. Throughout the entire work of the commission difficulty has been experienced in obtaining men who, in the opinion of the commission, were qualified to undertake the work. Without exception, all of the men in charge of work have

been thoroughly trained in science and technology; they have all had considerable experience in the practice of their especial lines of training, and no one of them has been influenced by partisan interest in the results.

Through the courtesy of Dr. Thomas Forsyth Hunt, dean of the college of agriculture of the University of California, the cooperation of several of the staff of the college of agriculture was obtained. The commission was fortunate in obtaining this cooperation, because of the especial experience of the collaborators. Owing to the "quasi legal" character of the commission, as distinguished from the activities of a board acting in behalf of a single party, Dean Hunt extended the facilities of his department and the services of his staff to the commission without compensation.

The cooperation of the department of physiology of the University of California was also obtained, through the courtesy of Dr. F. T. Gay, professor of pathology of the University of California.

Through the courtesy of the honorable the Secretary of the Interior, the facilities of the United States Bureau of Mines and its staff of experts were placed at the disposal of the commission, and some of the work undertaken was begun at their suggestion, while much of the work of the commission's staff was performed in the Bureau of Mines laboratories at San Francisco.

The cordial thanks of the commission are extended to Dean Hunt, Dr. Gay, and the honorable the Secretary of the Interior. The especial thanks of the commission are due to Dr. F. G. Cottrell, chief chemist, and Dr. L. H. Duschak, chemical engineer, of the United States Bureau of Mines, for their generous and valuable cooperation. The commission desires to extend its thanks to all of the staff for their painstaking and willing assistance and service.

The investigations of the commission were carried on by the following staff:

Ralph A. Gould, in general charge of investigations in consultation at frequent intervals with the other members of the commission.

Arthur E. Wells, metallurgist and chief chemist in charge of smelter investigations and field work.

C. B. Dutton, special legal agent, United States Bureau of Mines.

J. W. Blankinship, plant pathologist.

Wyatt W. Jones, plant pathologist.

R. W. Doane, professor of entomology, Leland Stanford Junior University.

Charles F. Shaw, professor of agronomy, college of agriculture, University of California.

E. E. Free, agronomist and soil expert.

C. M. Haring, D. V. M., professor of veterinary science, [illegible] agriculture, University of California.

Karl F. Meyer, D. V. M., professor of bacteriology and protozoology, college of medicine, University of California.

The Chemists' Club Library, bibliographers.

G. C. Bartells, jr., chemist, United States Bureau of Mines.

N. M. Porter, clerk of the commission.

Assisted by the following:

G. N. Libby, chemist and assistant metallurgist.

H. H. Bartells, chemist.

Bryant S. Drake, chemist.

J. D. Enas, chemist.

H. L. Long, chemist.

R. J. McKay, chemist.

R. W. Noreen, chemist.

E. P. Roleson, chemist.

Ralph W. Brown, assistant to agronomists.

William LaGrange, assistant to veterinarians.

J. H. Collier, statistical assistant.

D. C. Allen, field assistant.

H. G. Asseltine, field assistant.

I. Dickson, field assistant.

D. L. Hollingsworth, field assistant.

J. W. Norton, field assistant.

L. L. Patterson, field assistant.

PRELIMINARY INVESTIGATIONS OF THE COMMISSION.

Fully realizing the importance of the questions at issue and the results to be obtained by an impartial review and investigation of the subject as a whole, the commission decided to take nothing for granted in its collection of data concerning the area affected, but to obtain information at first hand, and thereby to be in a position to draw its conclusions impartially and to present its findings without bias.

A canvass of the situation as it existed at the time of the organization of the commission was made, and a preliminary plan of campaign was mapped out. This plan included, first, a review of the legal record of the case; second, a review of the scientific and technical data collected by the smelter company; and, third, a review of the scientific and technical data collected by Solano County.

From the information collected in this preliminary inquiry the commission concluded that much of the previous work of each of the parties to the suit had been done at cross purposes, and that little real information was available upon which to base a conclusion which would be equitable or scientifically justified.

Many of the complaints relative to conditions had been made in good faith by the residents of the area affected, upon the belief that

"smelter smoke" was the cause of the general lack of vigor displayed by the vegetation and was the main factor in the maintenance of an offensive smell in the area, which in this and other reports is designated as the smoke zone. Many of the answers given by the company to these complaints were simple denials that the trouble, whatever it was, was due to "smelter smoke." Some effort had been made by the company, at various times, to determine the specific causes of some of the registered complaints, but, as often happens in cases of this sort, the data collected were obtained for possible use in the defense of damage cases, and were, as a consequence, not freely discussed with the complainant for his enlightenment. Much crimination and recrimination had been indulged in to the detriment of the good will which should exist between industrial plants and the residents of the country surrounding them, and to the delay in reaching a definite, if not an amicable, settlement of the differences which existed.

While the large majority of the complainants of the smoke zone are undoubtedly honest in their belief that the smelter is the cause of many of their misfortunes there can be no doubt that others in ascribing their troubles to smelter smoke are actuated by ignoble motives. In the absence of positive and accurate knowledge on the subject, and with inability to properly correlate his observations, the layman can not be expected to arrive at true causes of obvious effects which, even to experts trained to observe and correlate their observations, are not only difficult, but sometimes impossible of accomplishment.

The farmer, not familiar with technical or scientific matters, observing peculiar markings on his crops in the vicinity of a smelter, very naturally blames the smoke as the cause of trouble. He may know nothing of the quantity or nature of the material handled by the smelter; he may not be able to identify the "smoke" when he smells it; but he does know that in many cases smelters are a cause of damage to the vegetation in the areas immediately surrounding them. It is, therefore, much easier for him to blame the smelter than it is to investigate carefully and learn positively the actual cause of the trouble which he sees. It is also too much to expect that the average farmer will find the time to devote to a detailed study of plant diseases and the various natural elements that constantly menace his crops and trees. When the average farmer has really become familiar with the subject, he is most reasonable and guarded in any statements he may make that "smoke" is responsible for all of his ills. With such an estimate of the usual intelligent citizen of this country, the commission has undertaken its labors in a spirit of helpfulness to both the farmer and the smelting company.

Looking at the questions as presented in the stipulation from a broad point of view, the commission has done some work that might have been left undone but for its desire to cover all phases of the subject with a view to the general good, and the commission feels that all its investigations have been conducted with a fully premeditated objective point as a goal. The commission has been as much interested in causes which can in no way be attributed to the smelter, or due to its operations, as it has in causes which are directly traceable to the smelter and due to its operations. The commission feels that it has investigated thoroughly and in such a manner as to throw a maximum of light on every question of real or fancied damage or cause of damage, nuisance or cause of nuisance which exists in the area, in so far as the two parties to the suit are concerned. This has required extended study and investigation along many divergent lines of inquiry.

The smelter is enjoined from operating in such a manner as to be a nuisance. The questions naturally arise—What conditions are necessary of fulfillment to produce a nuisance from the smoke of the Selby smelter? What conditions exist in the affected area? Do the existing conditions correspond with the required conditions?

It has been a matter of some difficulty for the commission to fix in its own mind just what conditions constitute a nuisance, as implied by the injunction decree and stipulation. Realizing the inalienable right of all persons to the peaceful enjoyment of life and property, the commission has endeavored to be most liberal in its construction and interpretation of the meaning of the word "nuisance."

Approaching the subject from this point of view, the commission undertook to determine the conditions which are necessary in order that the emanation from a smelter shall annoy or give trouble to persons or things or do injury to them. To determine these, it is necessary to know first and foremost the constituent parts of smelter smoke. Inasmuch as smelters vary in the kind of materials handled and, as a consequence, in the kind of smoke discharged, it is necessary to make inquiry into the composition of the smoke of the smelter concerned in this proceeding.

THE ATTITUDE OF THE RESIDENTS OF THE SMOKE ZONE.

For the purpose of informing itself on the attitude of the residents of the smoke zone in the matter of the existence of a nuisance or the existence of possible injury to crops and animals in the area, the commission personally interviewed a number of the residents of the smoke zone and availed itself of the services of C. B. Dutton, special legal agent of the United States Bureau of Mines, for an extended inquiry.

By this investigation it was sought to determine to what extent the elements of influence and suggestion entered into the complaints from the residents of the smoke zone and the feelings of the residents as to the existence of such nuisance.

Mr. Dutton was commissioned to interview the residents of the smoke zone in as thorough a manner as possible and to obtain their ideas as to the existence of a nuisance. He was directed to talk freely with the citizens concerning the aims and purposes of the commission, to give all the information he could as to any specific questions propounded to him, and to establish, in every possible way, a cordial relationship and spirit of helpfulness between the residents of the area and the commission and its agents or employees. Mr. Dutton's task consumed a period of about six weeks, during which time he interviewed 169 individuals. This number comprised the greater proportion of the farmers of the smoke zone. Those farmers who were not interviewed could not be found at home nor could arrangement be made to meet them by appointment. The remainder of the interviews were had with persons in all walks of life in the city of Benicia. The number of residents of the city personally interviewed was 135.

It was developed by Mr. Dutton that considerable misunderstanding obtained in the area as to the work of the commission, its aims and purposes. With the possible exception of a few radicals, it is believed that the farmers of the smoke zone, as a result of Mr. Dutton's efforts, have been brought to understand that the commission has been working in their interest quite as much as in the interest of the smelter company, and that the results of its deliberations will be founded upon facts and conditions as they actually exist.

The opinions expressed by the residents of the smoke zone, as to the existence of a nuisance and injury from the smelter smoke, vary from the extreme of unreasoning radicalism to entire indifference. By far the greater number of persons interviewed have given honestly derived opinions, usually accurately expressed, and full credence is given to their statements. The more radical, however, have made statements that are so obviously at variance with what the conditions must have been, and their opinions are so palpably colored by motives of cupidity, that their statements are of no value in passing judgment on the attitude of the residents as a whole.

A considerable amount of the nuisance that has been claimed by the residents of the area to have existed in the past and to some extent to be existent at the present time has without doubt been due to a condition brought about by suggestion. It is well known that by continued reiteration a statement eventually becomes more or less fixed and magnified in the mind of the person who makes the reiteration, until the person really believes that the conditions said to exist do exist. How much of the honestly expressed opinion is

due to this element it is impossible to say, but that it is present is shown by the fact that no agreement, worthy of the name, can be found in the statements of many of the persons interviewed as to the conditions which have obtained at any given period within the area. No concordance of opinion as to any definite time or times when the smelter smoke was "bad" or "very bad" or "awful" or "not very bad" was observable in the statements made. The fact that some of the residents observe it at any given period and others do not could be accounted for by the well-known fact that some persons are more susceptible to certain odors than are others. In a community of 3,000 people, however, it is quite unlikely that an odor of any kind could be present to a degree sufficient to establish its presence as a nuisance if only 80 persons in the 3,000 could detect it, and detecting it, insist that it was present in sufficient amounts to be considered a nuisance.

There are two classes of odors that have been ascribed to "smelter smoke" by the residents of the smoke zone. The one is undoubtedly that due to the sulphur dioxide that exists in smelter smoke and the other is just as surely that of certain products resulting from the refining of petroleum, the so-called "oil smell." In the descriptions of the odors they have experienced from time to time, and in detailing the sensations produced by those disturbing odors, many of the persons interviewed have described the odor of the one class and the symptoms produced by the other class, and vice versa. Others have described the presence of smelter smoke when the existing atmospheric conditions were such as to absolutely preclude the presence of an odor from either smelter smoke or oil products. They have also declared the presence of smelter smoke at times when the analysts of the commission, all trained men and thoroughly familiar with both odors, not only could not detect the odor by the sense of smell, but could not detect measurable quantities of sulphur dioxide in the atmosphere by chemical analysis with the most delicate of methods.

Concerning that part of the alleged nuisance that is caused by the presence of objectionable and ill-smelling gases, the consensus of opinion of the residents of the smoke zone is that there is slight, if any, objection at the present time to any pollution of the atmosphere by "smelter smoke." Under extreme conditions and to especially sensitive persons, "smelter smoke" may occasionally be smelled in the area, but to the fair-minded person such occasional occurrences do not prevent the enjoyment of life, nor are they detrimental to the health of the community. As to the conditions that existed prior to the issuance of the injunction decree, or indeed prior to the signing of the stipulation whereby the commission was organized, nothing can be said in this report except the hearsay and unsupported state-

ments of the residents of the smoke zone. From these statements it is possible to believe that previous years might have shown periods when the smelter smoke was smelled for longer periods of time and possibly more often; but, in the light of the investigations of the commission, it is highly improbable that such was actually the case, as the output of sulphur dioxide from the smelter, as will be discussed later, has gradually increased for the past five years.

Concerning that part of the nuisance claimed to exist that is caused by or made up from damage to plant and animal life, the consensus of opinion of the residents of the smoke zone is that at the present time the smelter is doing no damage. Some of the farmers of the smoke zone, however, feel that even now there are times when damage is done to stock and that occasional injury results to plant life. The major part of the agricultural community hold that the accumulation of damage to the land through the years when damage was claimed to have been great, constitutes a positive handicap to profitable working of their farms at the present time. The almost universal belief of the farmers is that the soil has been poisoned by the smoke. There is a strong feeling that horses were badly affected by the smoke up to three or four years ago, and, although no new cases seem to be developing, the old ones have not recovered, and to that extent a nuisance is maintained by the smelter at the present time. The fact that the smelter company has paid claims for animals, where death was reputed to be caused by smelter smoke, without investigation of the cases, is undoubtedly responsible for some of this feeling. The above must not be construed into an intimation that damage has not been done to animals in the past. Such action on the part of the smelter company is more reprehensible than the conduct of those residents of the smoke zone who insist that they have suffered damage, but are not willing to permit investigations which will positively establish such damage. The policy that "buys off" trouble, as the most expedient commercial method for abating it, has been responsible for much of the smelter litigation of this country and the intense ill-feeling that unfortunately exists toward smelters in many smelter communities. The principle that right is on the side of the man with the biggest guns is fast becoming an obsolete idea in modern business and is being replaced by equity and open and above board dealings.

CONDITIONS AT THE SELBY SMELTER.

SMELTER SMOKE.

The smoke of the Selby smelter is composed of three different classes of material—dust, fume, and gases. The dust consists of solid particles of mineral substances or compounds which are given

off during the metallurgical operations. These particles are always in the form of solids, as distinguished from liquids and gases. The fume consists of minute particles of solid matter or liquid matter, or both, which are evolved through the metallurgical processes in the form of gases or vapors and which are subsequently condensed to solids or liquids by reason of the changes of temperature to which they are subjected in their progress through the furnaces and flue system of the plant. Except atmospheric air, which constitutes over 95 per cent of the volume, the gases which are present in the smoke have been evolved by the metallurgical process as gases and remain in the gaseous condition throughout their progress through the furnaces and flue system of the plant.

The dust, being solid matter, is visible to the eye when it issues from the stacks of the smelter into the atmosphere. The fume, provided the temperature at the top of the stack is sufficiently low, is also visible to the eye when it emerges from the stacks. If the temperature is not sufficiently low to condense the fume from its gaseous and invisible condition as it issues from the stack, contact with the atmosphere soon accomplishes the condensation, and the fume becomes visible.

The gaseous constituents of the smoke are invisible at all times and always exist as gas. The constituents of Selby smelter smoke that may possibly contribute to a nuisance or produce injurious effects within the smoke zone are sulphur dioxide, which is present in the invisible portion of the smoke to a maximum extent of 1.5 per cent, compounds of lead, arsenic, and sulphur trioxide, and flue dust, which make up the greater portion of the visible constituents of the smoke.

For a number of years after the operations of the present smelter began little attempt was made to eliminate or recover the constituents of the smoke that made it visible, although it was known that the dust and fume contained substances that were of monetary value.

Plate I fairly represents the general appearance of the smelter prior to 1905, although taken on a day during the past year when the smelter, at the request of the commission, returned to its practice of the period before 1905.

BLAST-FURNACE SMOKE.

As progress in the science of metallurgy was made it came to be realized by the smelting company that efficient and profitable operation of the plant demanded that as much as possible of this visible element of the smoke be saved. It was learned, too, that certain of the constituents which made up the visible portion of the smoke were of such a character as to be injurious to animals which lived in an atmos-

phere sufficiently contaminated by this visible element of the smoke or which fed upon forage upon which this dust and fume had been deposited in sufficiently large amounts. The particular substances which cause this injury are the compounds of lead and arsenic existing in the smoke. Whether or not as a result of a desire to operate efficiently or whether as a result of the filing of the suit for injunction, perhaps as a result of both, the smelting company in March, 1908, completed the installation of an apparatus that was designed to eliminate the visible smoke given off from the stack into which the blast-furnace smoke was discharged. This installation,[a] known as a bag house, operated successfully, eliminating all of the visible portion of the blast-furnace smoke, so that from this stack only invisible gases issue at the present time.

Plate II, *A*, and Plate II, *B*, illustrate the conditions of the blast-furnace stack before and after the installation of the bag house, and Plate II, *C*, shows a general view of the smelter stacks as they appeared subsequent to 1908.

PARTING-RETORT FUMES.

One of the metallurgical processes of the smelter used in connection with the refining of gold and silver produces large volumes of the fume of sulphuric acid. The vapor or fume from sulphuric acid when in its concentrated form is extremely destructive to animal and vegetable tissue. Fortunately for the smelter and for the surrounding country these fumes are very heavy, and, except in high wind, do not carry far from the point at which they may be discharged into the atmosphere. Unfortunately for the smelter the avidity with which these fumes attack all sorts of organic matter and most metals made their elimination impracticable. In order to carry on that part of the refining process in which sulphuric acid is used these fumes were discharged into a low stack to prevent, as far as possible, their wide dissemination and to confine them to an area immediately contiguous to the smelter itself. It may be remarked, in passing, that these fumes were the chief cause of the complaints that were constantly brought out at Vallejo Junction a number of years ago. At about the same time (1906–7) there was brought into successful commercial operation a process designed for the precipitation of suspended particles of matter, either solids or liquids, by means of electricity. The process is known as the "Cottrell electrical precipitation process."

It was found experimentally that the Cottrell process effectually precipitated these fumes, and the installation of a plant sufficient in

[a] See A. E. Wells's report on "Conditions in and around the Selby smelter and the Selby 'smoke zone,'" pp. 63–81.

GENERAL APPEARANCE OF SELBY SMELTER PRIOR TO 1908.

A. BLAST-FURNACE STACK BEFORE INSTALLATION OF BAG HOUSE.

B. BLAST-FURNACE STACK AFTER INSTALLATION OF BAG HOUSE.

C. STACKS OF SELBY SMELTER AFTER CHANGES TO PLANT IN 1908.

size to handle all of them completely eliminated this element from the visible smoke issuing from the plant. This installation was in working order at about the same time the bag house was placed in operation.

Plate III, *A*, and Plate III, *B*, illustrate the appearance of the "parting-retort" stack before and after the installation of the Cottrell process.

Plate IV, *A*, shows a general view of the smelter stacks at the time the commission was organized.

ROASTER SMOKE.

There remained at the plant a single stack from which visible smoke issued. This was known as the "roaster stack." The smoke emanating from this stack resulted from the metallurgical processes known as "roasting," and owing to the type of furnace used contained, aside from its gaseous constitutents and the dust and fumes derived from metals, comparatively large amounts of fume of sulphuric acid which was generated during the roasting. In contrast with the smoke derived from the blast furnaces the smoke of the roaster stack was extremely difficult to clear of its visible element. The blast-furnace smoke contains only traces of sulphuric acid fume, which, although it does have an appreciable effect on the fiber of the bags through which the smoke filters in its clearing process, does not by any means prohibit the use of bags for this purpose. The roaster smoke generated by the type of furnace then in use contained such large quantities of sulphuric acid fume that it quickly destroyed the bags through which it was passed in an attempt to clear it. It was therefore impracticable, not to say impossible, to clear the roaster-stack smoke of its visible element in this way. In an effort to find a method for the elimination of the visible element of the roaster-stack smoke the smelter company experimented for some 18 months in an endeavor to adapt the Cottrell process to this purpose. After nearly $20,000 had been expended in this work the attempt was abandoned.

About this time an improved roasting furnace, known as the Dwight & Lloyd sintering machine, was given to the smelting industry. One of these machines was installed at the plant as an experiment, and the necessary changes were made in the metallurgical processes of the plant to permit its use. The use of this machine required a preroasting of the ores received at the plant, which contained large amounts of sulphur. Arrangements were made by the Selby Smelting & Lead Co. with an acid-making plant to receive and preroast these high-sulphur ores (California sulphurets) and then deliver them to the smelter. The new machine and new plan of

handling the ore worked well, and gradually, as the plant could be remodeled to accommodate them, additional Dwight & Lloyd machines have been installed and the old-type roasters (Ropp roaster) have been taken out. The Dwight & Lloyd machine, although it performed much the same office as the Ropp roaster, did not, on account of the different principles upon which its operation is based, produce sulphuric-acid fume to an extent anywhere near that of the older type of machine.

Upon assuming its work the commission found that the smelter was using two of these Dwight & Lloyd machines and one of the old-type (Ropp) roasters, with preparations being made for the installation of a third Dwight & Lloyd machine. It is necessary, therefore, to consider the composition of the smoke eliminated from the Selby smelter at the time the commission began its work—that is, May, 1913—and during the succeeding period up to May 15, 1914, when the commission finished its studies on the composition of the air of the smoke zone.

SUMMARY.

To summarize the conditions found by the commission when its work of investigation began, we note: First, the blast-furnace stack was giving off only invisible gases, the visible part of the smoke being removed by the blast-furnace bag house; second, the parting-retort stack (that to which the heavy sulphuric-acid fume is conducted) was giving off only invisible gases, all of the visible part being removed by the Cottrell electrical precipitation process; and, third, the roaster stack was giving off visible smoke.

As is made clear in the report of A. E. Wells in his detailed discussion of the metallurgical processes of the plant,[a] the invisible gases given off by the blast furnace are made up of the gases of the atmosphere together with carbon monoxide, carbon dioxide, a relatively small amount of sulphur dioxide, and a much smaller amount of the fume of sulphuric acid. During the course of its travels through the flue system most of the sulphuric-acid fume originating in the blast furnace combines with the metal constituents of the smoke to form solid compounds which, together with the other solids, are eliminated by filtration through the bags.

The invisible gases, therefore, that escape through the blast-furnace stack into the atmosphere are water vapor, nitrogen, oxygen, carbon monoxide, carbon dioxide, and a small amount of sulphur dioxide—less than 0.04 per cent by volume. Of these escaping gases the sulphur dioxide is the only one that is of any significance in relation to its liability to injure plants or animals or constitute a nuisance to man. In the small amounts in which it occurs in this

[a] "Conditions in and about the Selby smelter and the Selby 'smoke zone,'" pp. 63-81.

A. "PARTING-RETORT" STACK BEFORE INSTALLATION OF ELECTRICAL PRECIPITATION PROCESS.

B. "PARTING-RETORT" STACK AFTER INSTALLATION OF ELECTRICAL PRECIPITATION PROCESS.

A. GENERAL VIEW OF STACKS AT TIME COMMISSION WAS ORGANIZED.

1, blast-furnace stack; 2, parting-retort stack; 3, roaster stack.

B. ROASTER GASES LEAVING SMELTER UNFILTERED.

C. ROASTER STACK AFTER GASES WERE FILTERED.

particular case it has practically no influence on the main source of nuisance, if such is maintained by the smelter, in the area in question. The invisible gases from the blast-furnace stack can therefore be dismissed as a factor that contributes to the violation of the injunction decree.

The invisible gases coming from the parting-retort stack are practically nil. The efficiency of the Cottrell-process apparatus, which amounts to 99.5 per cent, eliminates any source of nuisance or injury from the parting-retort stack, in so far as the smoke zone is concerned. All of the sulphuric-acid fume coming from the parting retorts is passed through the Cottrell-process apparatus and is condensed to liquid sulphuric acid.

The one remaining source of atmospheric pollution is the roaster stack. Aside from the visible part of the smoke furnished by the roasting process, large amounts of sulphur dioxide are evolved. Except for the atmospheric air, which constitutes 98 per cent of the volume of the smoke, this sulphur dioxide is the principal part of the invisible part of the smoke produced by the roasting of ores at the Selby smelter.

CLEARING OF ROASTER-STACK SMOKE.

The amount of dust and fume produced in the roasting process under the conditions of operation obtaining when the commission began its work was about 5,000 pounds per day of 24 hours, whereas the amount of sulphur dioxide eliminated was in the neighborhood of 60 tons per day of 24 hours (equivalent to 30 tons of sulphur); whereas the maximum quantity of sulphur dioxide that could possibly be eliminated by the smelter was 90 tons per 24-hour day.

The commission early came to the conclusion that the smelter company should make an attempt to eliminate the visible portion of the roaster-stack smoke, as a result of which the following correspondence passed between the commission and the Selby Smelting & Lead Co.

SAN FRANCISCO, *October 25, 1913.*

SELBY SMELTING & LEAD CO.,
San Francisco, Cal.

GENTLEMEN: In connection with the studies being made by the commission relative to conditions in Solano County, it is desired to study the composition of the atmosphere when it is mixed with smelter smoke which has been freed from fume.

With this end in view the commission recommends that you install at the smelter and put into operation at the earliest possible date:

1. A bag house or an electrical precipitation plant for the removal of the suspended matter from the gases coming from the sintering machines.
2. An electrical precipitation plant for the removal of the sulphuric-acid vapor and suspended matter in the gases coming from the Ropp roaster.

Respectfully,

(Signed) RALPH A. GOULD,
Secretary.

SAN FRANCISCO, *October 28, 1913.*

SELBY SMELTER COMMISSION,
Monadnock Building, San Francisco, Cal.

GENTLEMEN: We beg to acknowledge receipt of your favor of the 25th instant, in regard to the desire of the commission to study atmospheric conditions in Solano County freed from fume, and in reply will say that at the earliest practical date we will endeavor to free our smoke from all fume, as desired by the commission.

Very respectfully,

(Signed) E. B. BRADEN,
Vice President, Selby Smelting & Lead Co.

After due consideration of the recommendation of the commission, the Selby Company decided upon the installation of a bag house for use in connection with the smoke from the Dwight & Lloyd sintering machines.

In March of 1914 the projected bag house was completed, and, after overcoming the numerous mechanical difficulties always encountered in the operation of installations of this kind, has been in successful operation, thereby clearing the roaster-stack smoke of its visible element. Since April, 1914, the smelter has given off no visible smoke, except during very short periods of time, when, for purposes of resetting the bags or overcoming some mechanical trouble, it has been necessary to allow the smoke to escape without passing it through the bag house.

Plates V, *A*, and IX, *B*, show the general appearance of the stacks of the smelter as they are at the present time (Nov. 5, 1914).

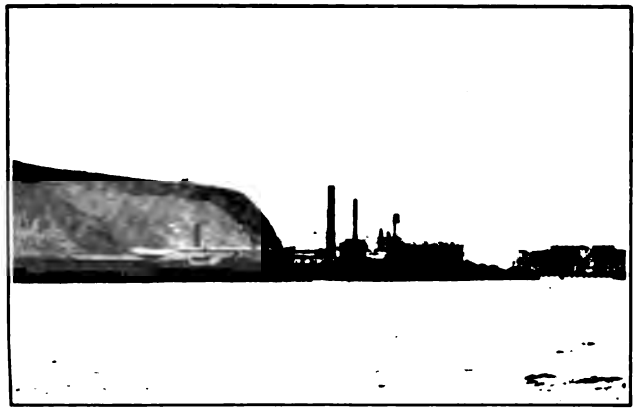
It must be borne in mind that the smelter company, although they still have one Ropp roaster installed, can not pass the smoke from it through this bag house. This Ropp roaster is used for a special purpose and only during the so-called open season. If the metallurgical practice of the plant requires the operation of this Ropp roaster at other times, apparatus of special design will be required to eliminate the visible part of the smoke from this furnace.

SULPHUR DIOXIDE AS A FACTOR IN THE MAINTENANCE OF A NUISANCE.

SULPHUR DIOXIDE OUTPUT OF THE SMELTER.

As a consequence of the elimination of the visible element of the smoke from the Selby plant, any injury or nuisance that may be created by or be due to the presence of compounds of lead, arsenic, or other metals, or to any other constituent of the visible element of the Selby smelter smoke is nil. The only nuisance or injury that can possibly be maintained or produced under the present régime of operations is that which may be due to the sulphur-dioxide gas that escapes from the roasting of the ores.

The question before the commission, therefore, is this—Does the sulphur dioxide at present being discharged from the stacks of the



A. GENERAL VIEW OF SELBY SMELTER, SEPTEMBER, 1914.

B. SAMPLING PLATFORM, ROASTER STACK.

C. OUTSIDE OF BLAST-FURNACE BAG HOUSE.

Selby smelter constitute a nuisance to the citizens of the region about Benicia, either by causing personal inconvenience or disagreeable experiences or by doing injury to crops, or to the soil of the area, or to domestic animals or other property of the residents of the smoke zone?

It should be remarked in passing, for the benefit of the layman, that when a given weight of ordinary sulphur burns in the air or in any medium in which sulphur dioxide is formed there is produced just double the weight of sulphur in the form of sulphur dioxide. Thus 1 ton of sulphur in burning forms 2 tons of sulphur dioxide; this 2 tons of gas occupies a volume of approximately 12,000 cubic feet at ordinary temperatures and pressures.

The metallurgical reports of the smelter show that during the "open season" immediately preceding the organization of the commission—that is, from November 15, 1912, to March 15, 1913—the average quantity of sulphur given off by the smelter was 29.3 tons per 24-hour day, or 58.6 tons of sulphur dioxide. The maximum amount of sulphur given off during any one day of this period was 43.2 tons, or 86.4 tons of sulphur dioxide, while the smallest amount eliminated was 11 tons of sulphur, or 22 tons of sulphur dioxide. This was during the season when the smelter could operate without regard to the terms of the injunction.

Although it was possible for the smelter to give off 90 tons of sulphur dioxide per 24-hour day during this period, the actual average output was only 65 per cent of the maximum possible amount. During the year in which the commission has been investigating the questions before it the roasting processes of the plant have been remodeled, until at the present time four Dwight & Lloyd sintering machines and one Ropp roaster constitute the roasting equipment of the smelter. The maximum quantity of sulphur dioxide which can be eliminated from this equipment through the roaster stack is 120 tons per 24-hour day. The influence of this increased possible output of sulphur dioxide on the maintenance of a nuisance in the smoke zone will be discussed later.

The smelter's average daily output of sulphur for each month of the years 1910 to 1913, inclusive, and the first four months of 1914 is shown by the vertical lines in figure 1. For example, the average daily output for the month of January, 1910, was 21.5 tons; for December, 1910, 31.5 tons, the minimum and maximum, respectively, for the year.

The connected circles show the output based on the daily averages for each year. It will be seen that the average daily output for the years 1910 to 1913, inclusive, and the first four months of 1914 was, respectively, 24.8, 25.4, 26.6, 24.4, and 28.3 tons. This is a small

output of sulphur compared with the enormous quantities emitted by many smelting plants.

It may be noted in passing, for the benefit of the layman, that the figures that show the amount of sulphur dioxide emitted from the smelter are calculated from the daily metallurgical reports of the smelter. These records are kept by the smelter to check the operation of the metallurgical processes. To the metallurgist they speak

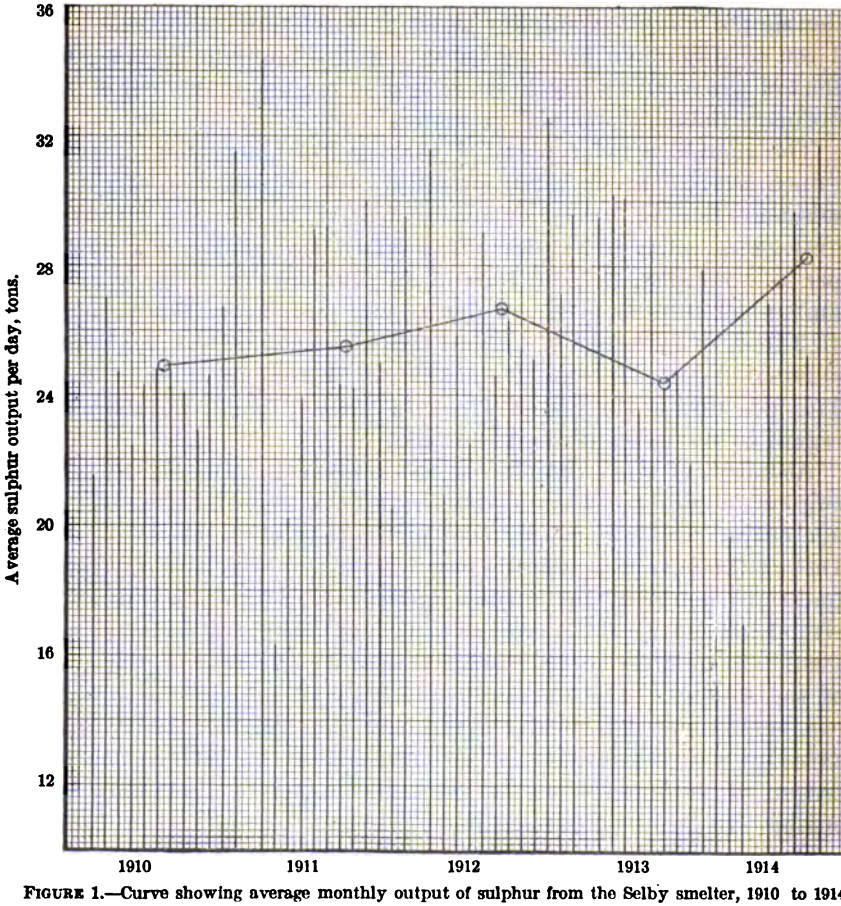


FIGURE 1.—Curve showing average monthly output of sulphur from the Selby smelter, 1910 to 1914. The heavy vertical lines represent sulphur output by months, the line farthest to the left representing the output for January.

a language of dollars and cents in the profitable operation of the plant. It may be contended that these metallurgical reports are not of value in the above connection because of a fancied belief that they can be manipulated to show anything the smelter company desires. This is not a fact. One obvious reason why these reports have not been tampered with or altered to suit the purposes of the smelter company is that until the organization of the commission

these reports have never been introduced as evidence in any of the litigation, and probably the smelter company entertained no expectation whatever that they would be so used. The figures representing the amount of sulphur dioxide emitted have been calculated from data that, as they stand on the metallurgical reports, are collected by the smelter for an entirely different purpose than that to which they have been put by the commission.

The graphic representation of the monthly sulphur output (fig. 1) shows that during the months of October, November, and December of 1913 the output of sulphur dioxide was very low. This low output was at the express request of the commission for the purpose of study during the end of the closed season and the beginning of the open season covered by the injunction.

FACTORS CAUSING DISTRIBUTION OF SULPHUR DIOXIDE IN THE ATMOSPHERE.

It may be contended that even though there was more sulphur dioxide emitted by the smelter during 1913 than in preceding years, it was not carried over the smoke zone because of the different wind directions and conditions of calm that existed in the area during that time as compared with the preceding years, and hence that the smoke was less noticeable. Such a contention, however, can not be maintained, for a study of the graphic representation of the wind conditions for the years 1911, 1912, and 1913 (figs. 2, 3, and 4) shows a striking similarity in these conditions during the three-year period covered.

The lines on these wind charts represent the percentage of time in each month during which the wind blew from the direction indicated. Although the names of the months are not given in the figures, the months are arranged to be read from left to right when facing the direction from which the wind blows. For example, during January, 1911, the wind blew, beginning with north and continuing around the compass, 0, 1.1, 32.7, 1.1, 7.5, 26.3, 4.3, and 0 per cent from the direction indicated. It was calm 27.4 per cent of the time.

During 1911 the wind blew from the southwest 54 per cent of the time, during 1912 there was southwest wind during 50 per cent of the time, and during the first nine months of 1913 the southwest wind blew 52 per cent of the time. During the same periods there was calm for 15 per cent, 16 per cent, and 11 per cent of the time, respectively, and the west wind blew 12 per cent, 12 per cent, and 20 per cent of and the time during 1911, 1912, the first nine months of 1913, respectively. In like manner the prevalence of wind from other quarters is in extremely close agreement.

Although these wind records have been collected by the smelter company and the commission has no means of absolutely checking

them, it is believed that they are accurate and reliable inasmuch as they make out a worse case against the smelter company than they would had it been the company's desire to manipulate the data. It should be remarked that such wind directions and observations as have been made by the commission's staff of observers check with the records taken by the smelter company during the course of the field work of the commission. Contention, if it is advanced, that differences in wind direction may account for any greater prevalence of

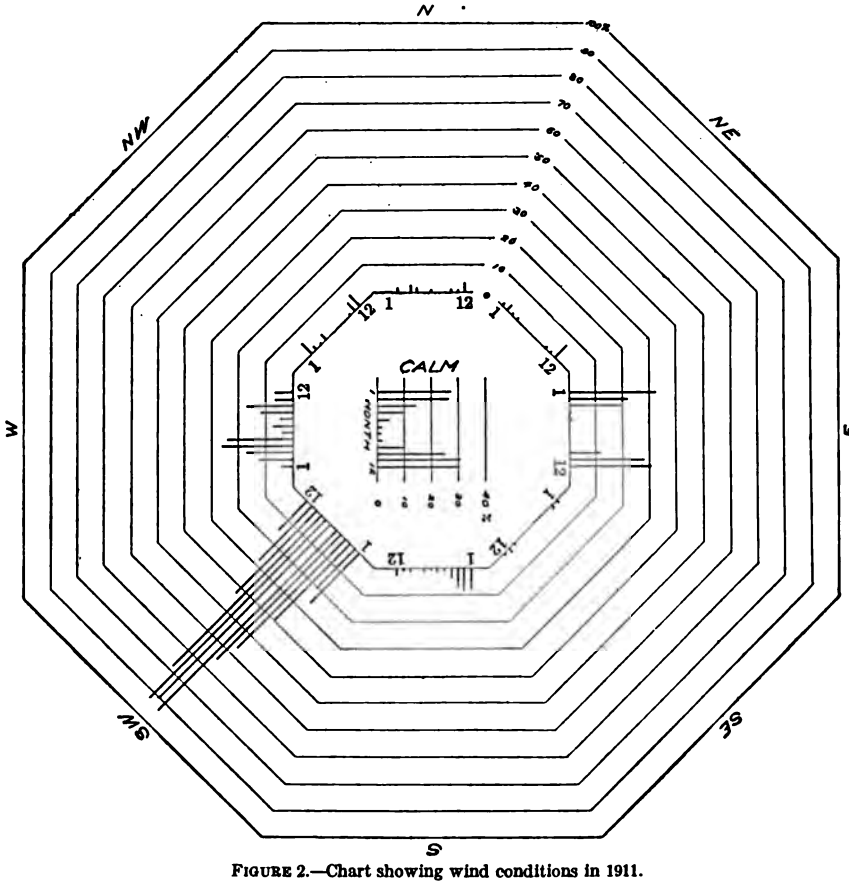


FIGURE 2.—Chart showing wind conditions in 1911.

sulphur dioxide in the atmosphere of the smoke zone in the years preceding 1913 can not, therefore, be maintained. The wind directions have continued to be the same in general and the amount of wind has been approximately the same during the three yearly periods.

Owing to the natural outline presented by the hills in the area and the hills on the Contra Costa County side of Carquinez Straits, there is formed a channel which plays an important part in the distribution and dissemination of the smoke from the Selby smelter. The prin-

cipal effect of this natural draw is to increase the movement of the smoke during periods of calm or very light winds from the west and southwest and perhaps to carry the smoke farther during periods of moderate or strong winds from these directions. During calms, smoke may drift over the area at any time, but with winds from any other direction than between south and northwest it is obviously impossible for the smelter smoke to pass over the smoke zone.

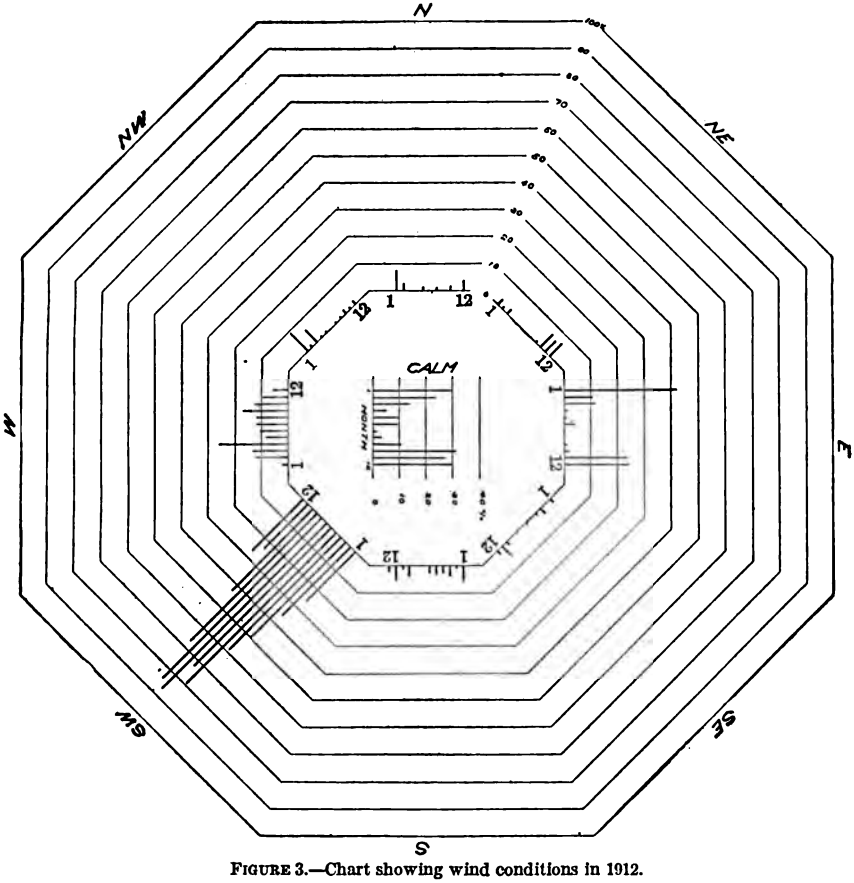


FIGURE 3.—Chart showing wind conditions in 1912.

It is obvious to all persons that, when the wind blows from the smoke zone toward the Selby smelter, the smoke can not be present in the smoke zone. It is just as obvious that when the wind blows from the smelter directly toward the smoke zone, then the smoke from the smelter may be present in the smoke zone. A line drawn from the smelter through the central portion of the smoke zone takes a general northeasterly course, so that any wind blowing from the south or from any point between south and northwest would be liable to carry the smoke into some part of the smoke zone. Plates VI, VII, and XXXVIII showing the Selby smoke zone illustrate this point.

SULPHUR DIOXIDE CONTENT OF THE ATMOSPHERE OF THE SMOKE ZONE.

GENERAL CONSIDERATIONS.

A study of the detailed notes taken by Mr. Dutton while interviewing the residents of the smoke zone inevitably gives one the impression that the smelter has been given a fairly clean bill of health by the very people who made the complaint that the injunction is

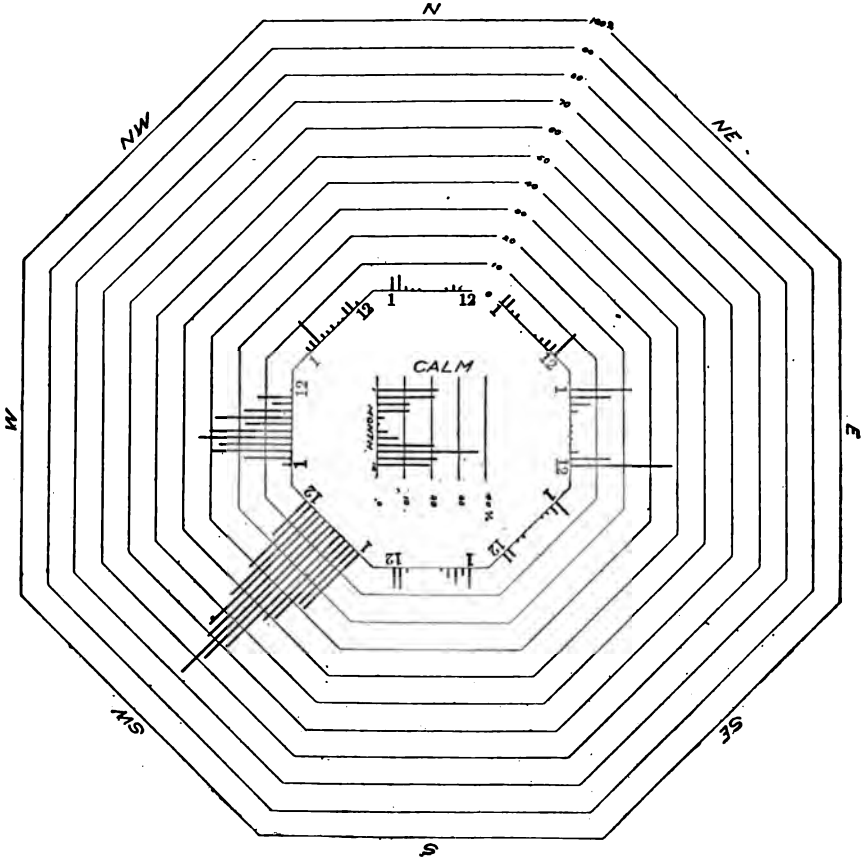
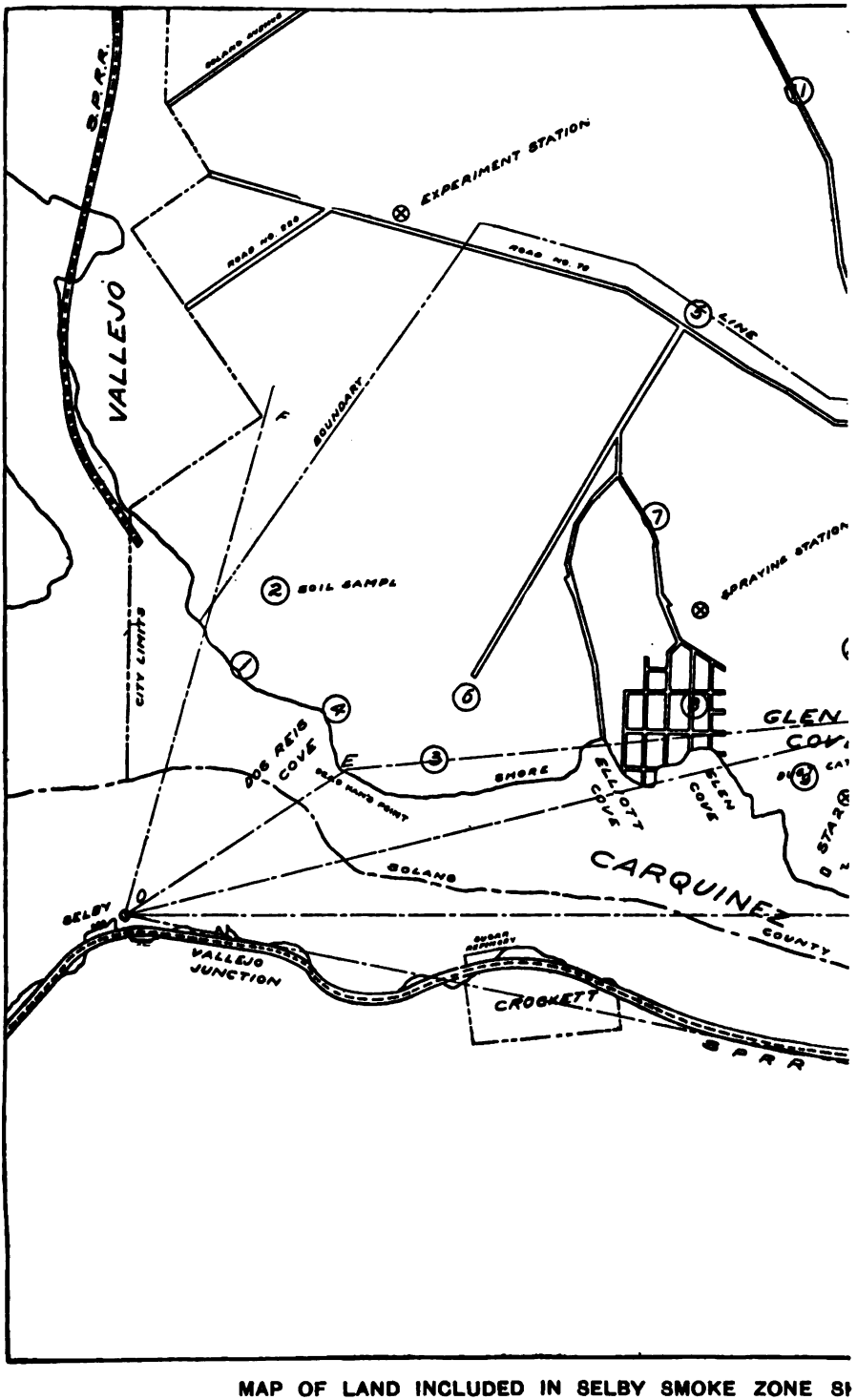


FIGURE 4.—Chart showing wind conditions in 1913.

being violated. It would be obviously improper, however, to base such a conclusion upon these statements alone. The incorrectness of many of the statements of residents of the smoke zone as to certain conditions being caused by "smelter smoke" must be evident to any person of even a small amount of knowledge of the processes carried on by the smelter and the properties of the constituent parts of smelter smoke. Certain statements are highly ludicrous and improbable, not to say impossible. It is also shown from the investigations of Mr. Dutton that statements of certain people of the smoke zone to the



MAP OF LAND INCLUDED IN SELBY SMOKE ZONE SI

effect that conditions are better than they were can not be taken as proof that conditions actually are better.

It transpires as a result of the investigations of the commission that the amount of sulphur dioxide that has been discharged from the smelter has gradually increased, year by year. It will be noted that during the first nine months of 1913, which nearly every one states has been the best year in the matter of freedom from smoke trouble, 10 per cent more sulphur dioxide was emitted from the smelter stacks than in the year 1910, when, according to the testimony of most of the residents, the nuisance was very great, and constituted a serious menace to the community. While the fact that many of the residents of the smoke zone have stated that 1913 has been the best year for several years does not prove that the smelter is not violating the injunction, these statements do point to the fact that the "smelter-smoke smell," which is one of the factors contributing to the nuisance, has in the minds of many abated to a large extent.

The commission has considered that one of the most important phases, if not the most important, of its work was to determine the composition of the atmosphere of the smoke zone as concerns sulphur dioxide. It was evident that this investigation would occupy some considerable time and the services of several chemists. After a considerable search throughout the United States for a man of proper qualifications, the commission selected Mr. A. E. Wells, of Salt Lake City, and tendered him the post of metallurgist and chemist to the commission, in charge of field and laboratory work. Mr. Wells is a graduate of the Massachusetts Institute of Technology and has had extended experience in metallurgical operations and smelter-smoke investigations. The commission feels itself very fortunate in having procured Mr. Wells's services and desires to state that much of the excellence of the many reports submitted to the commission is due to his keen grasp of the conditions and his recognition of the desires of the commission for a complete investigation of them.

The investigations conducted by Mr. Wells, under the immediate supervision of the commission, to determine the composition of the atmosphere of the smoke zone have been very extensive. So far as can be found by a careful search of the literature, the commission's work has been much more extensive and exhaustive than any heretofore attempted. In collecting such an immense amount of information the commission has been guided by a desire to know fully and absolutely the conditions at all times within the smoke zone. The period of investigation extended from September 17, 1913, to December 15, 1913, and from March 1, 1914, to May 15, 1914. There were engaged upon the work, aside from Mr. Wells, under whose direct superintendence it was prosecuted, eight chemists and six helpers.

During the entire course of the investigation especial attention was given to the metallurgical processes going on at the smelter, and the

amount of sulphur dioxide eliminated from the smelter during the tests in the smoke zone has been checked by the staff of the commission. Determinations were made when the wind conditions were the worst possible for the area and when the output of sulphur dioxide from the smelter was, by request of the commission, at a maximum. Other tests have been made when the smelter was entirely closed down with the wind conditions favorable and unfavorable to the smoke zone. Every attempt has been made to obtain these data under all possible conditions in order that maximum, average, and minimum figures might be obtained as to the sulphur dioxide content of the atmosphere of the smoke zone. That this has been accomplished is shown by the numerous figures which are given in Mr. Wells's report.

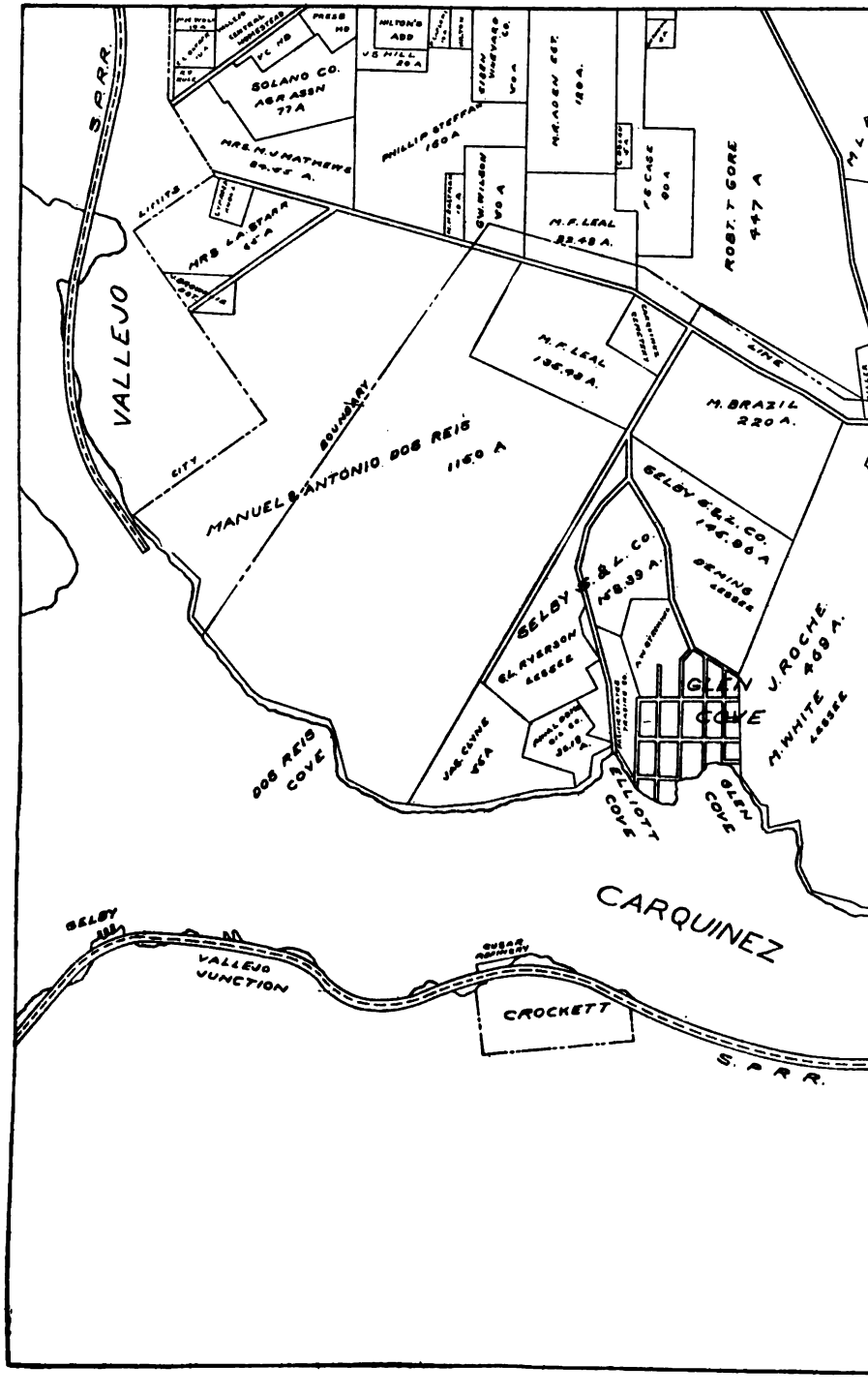
The collected data have been taken at all times of the day, except between the hours of 8 p. m. and 4 a. m. For the reason that the determination of sulphur dioxide depends upon the comparison of two colored solutions, work at night was not practicable. Some of the residents of the smoke zone made an especial point of the difference between the air at night and during the day, but observations of the wind directions during the night showed no more unfavorable winds at that time than during the early morning hours, and these latter are covered by the data collected. It was, therefore, obvious to the commission that little would be gained by taking samples at night.

METHODS OF DETERMINING SULPHUR DIOXIDE.

A careful review of the literature of "smelter smoke" failed to disclose any methods for determining sulphur dioxide which, in the opinion of the commission and its staff, would satisfy the requirements of the proposed investigations. It was found necessary, therefore, to develop a method of analysis that would fulfill the desired requirements, namely, instantaneous sampling, continuous or average sampling, a high degree of accuracy and rapidity of execution combined with ease in field manipulation. By combining the best points gathered from the literature with the experience of various persons who had engaged in similar work, a method for the determination of sulphur dioxide in the atmosphere was eventually evolved which answers all of these requirements. It is believed that the method finally adopted is by far the best yet used in work of this character, and that the results obtained are accurate and representative of the conditions which exist in the smoke zone in relation to sulphur dioxide.

ANALYTICAL RESULTS.

Two permanent observation stations, known as station 1 and station 2, were established in the smoke zone and chemists were placed in charge of them. These stations were selected so as to obtain, in so far as possible, the maximum amounts of smoke, in its most con-



MAP OF LAND INCLUDE

centrated form, which blew over the smoke zone. The location of the stations [a] was chosen after a consideration of data collected in various parts of the smoke zone prior to their establishment. These data were collected by means of an automobile laboratory, which was equipped for three purposes—first, to collect the data mentioned above; second, to collect data in various sections of the smoke zone simultaneously with those collected at the permanent stations; and, third, to collect data in various places contiguous to San Francisco Bay, subjected and not subjected to contamination by smelter smoke.

During the time between September 15, 1913, and May 15, 1914, a total of 4,862 observations or determinations of the sulphur dioxide content of the atmosphere of the smoke zone have been made under every condition which could, in the opinion of the commission and its staff, have any bearing upon the existence of a nuisance from the smoke of the Selby smelter anywhere within the smoke zone. Their distribution as to the direction of the wind is shown in the following table, together with the maximum, minimum, and average amounts of sulphur dioxide found.

The table gives a summary of the results of the 4,862 determinations made at the two permanent stations and with the movable automobile laboratory.

The maximum value of 7.1 parts per million was obtained at station 2, which, it will be noted, was situated on the high hills, 2½ miles from the smelter, at a time when a gentle breeze from the west was carrying the smoke stream from the smelter directly to this spot, and while the smelter, at the request of the commission, was sending out smoke at its maximum capacity. The legend <0.2 is to be read less than 0.2 part per million, or quantities too small to be determined by the analytical methods used.

Results of determinations of SO_2 content in atmosphere of smoke zone of Selby smelter.

Direction and force of wind.	Number of determinations.	SO_2 parts per million, by volume.		
		Maximum.	Minimum.	Average.
Blowing from smelter toward smoke zone.				
Slight west wind	1,114	7.10	<0.20	0.44
Moderate or strong west wind	1,252	1.25	< .20	.27
South or southwest wind	683	1.00	< .20	< .20
West or northwest wind	257	.60	< .20	< .20
Total	3,306	.....	.....	.28
Blowing from smoke zone toward smelter.				
East or southeast wind	714	.80	< .20	< .20
North or northeast wind	317	.40	< .20	< .20
Northwest wind	525	.60	< .20	< .20
Total	1,556	.....	.....	< .20
Grand total	4,862	[b] 7.10	[a] < .20	.22

[a] The positions of these stations are shown on the map comprising Plate XXXVIII.
[b] Maximum.

As addendum to this table it may be noted that of the 2,841 determinations made during a period of eight months within the limits of the city of Benicia no one showed a sulphur dioxide concentration as high as 2.5 parts per million, while of the 4,862 made in the whole smoke zone only 6 showed a concentration higher than 3 parts per million. These results are significant when attention is called to the fact that it is impossible to detect by the sense of smell sulphur dioxide when it is present in the atmosphere in a concentration below 3 parts per million.

DISCUSSION OF RESULTS.

It is impossible to discuss the data concerning the sulphur dioxide content of the atmosphere of the smoke zone and other places with any degree of fullness without going into innumerable details. It is not strictly accurate, for example, to hold average data as representative nor to assume that positive conclusions can be drawn from them. The mass of detail that must necessarily be considered in drawing conclusions would be most tiresome to the layman if he attempted to follow it, and it has been considered by the commission advisable for the purposes of this report not to go into such a detailed discussion here, but leave that, for those who are interested, to the detailed report. In the discussion that follows, therefore, those figures that are quoted will be such as are, in the opinion of the commission, the proper ones for a simple and correct exposition of the question. It is the aim of the commission to base its findings upon actual facts scientifically collected and determined, but to discuss these findings and the collected data in nontechnical terms and in such a way as to be easily followed by the layman.

A study of the detailed notes in connection with the observations made during the existence of slight west winds—that is, when the smoke is gently drifting in practically its full volume over the area—discloses that 21 determinations were made in the area that showed more than 2 parts SO_2 per million parts of air.[a] This represents 1.8 per cent of the total observations taken during the worst wind conditions for the smoke zone. Further study of the detailed notes shows that these 21 determinations average 3.6 parts SO_2 per million parts of air, including one single determination that was as high as 7.1 parts SO_2 per million parts of air. The data show that these 21 determinations represent the presence of more than 2 parts SO_2 per million parts of air for a total of 220 minutes, or 3 hours and 40 minutes, during an elapsed time of eight months.

In the light of the investigations carried on to determine the sensitiveness of the average person to sulphur dioxide, it does not

[a] In the discussion of the concentration of sulphur dioxide in the atmosphere and elsewhere, the chemical symbol for sulphur dioxide is frequently used, thus, SO_2.

appear that sulphur dioxide in the concentration mentioned above, for the small proportion of time in which it could possibly have been present in the atmosphere would constitute a serious inconvenience or menace to the health of any community, for it was established in the experiments above referred to that the average person could not even detect the presence of any foreign substance in the atmosphere when the amount of sulphur dioxide was below 3 parts per million of air and that such a concentration was not considered a nuisance by a single one of the 60 subjects experimented upon.

If we assume for purposes of discussion that every resident of the smoke zone is sensitive to the odor of sulphur dioxide to a degree double that of the average person, and if we further assume that such persons can detect and even consider as a nuisance an atmosphere containing 2 parts SO_2 per million, then the smoke zone could have been subjected to such a nuisance from the Selby smelter smoke during 0.06 per cent of the time from September 15, 1913, to May 15, 1914. This means that had the smoke appeared with perfect regularity and had a slight west wind prevailed during the entire time, the smoke would have been smelled and have been a nuisance to the entire population of the smoke zone for 4.5 minutes in every 24 hours from September 15, 1913, to May 15, 1914. This puts the case in its most exaggerated form and is based on the assumptions that the residents of the smoke zone are able to detect 2 parts of SO_2 in a million parts of air and that the wind is continuously blowing gently from the west.

Under the actual conditions, when a concentration of 3 parts of SO_2 per million parts of air or more existed, the smoke would have been objectionable for a period of 44 minutes during the eight months.

As a matter of fact, the average person can not even detect—much less consider a nuisance—the presence of sulphur dioxide in the atmosphere when the concentration is below 3 parts per million, and the wind records taken by the field staff during this period show that light west winds blew less than 20 per cent of the time. It therefore follows that the attentive person would be aware of the presence of sulphur dioxide in the atmosphere of the smoke zone during 16 seconds of time each day, or for a total period of 65 minutes in the eight months during which the investigations of the commission were in progress.

These conclusions based on the mean concentration of sulphur dioxide in the atmosphere of the smoke zone show that it is impossible to conclude that the Selby smelter is maintaining a nuisance by emitting sulphur dioxide into the atmosphere in such quantity as to produce a disagreeable or objectionable odor or to disagreeably or injuriously affect the throat or lungs of human beings or domestic animals living within the smoke zone.

The commission is of course cognizant of a certain weakness in a method of arriving at conclusions based on the average content of sulphur dioxide in the atmosphere of the smoke zone, for it is well known that the instances of smelter smoke damage are the result of bathing the growing vegetation, ordinarily for short periods of time, with streams or puffs of smoke of high sulphur dioxide content direct from the smelter stacks. It therefore follows that the maximum concentrations of sulphur dioxide found by the commission's staff in the smoke zone must receive due consideration.

The investigations of Mr. Wells and his staff of chemists show six occasions when the atmosphere around station 2 contained over 3 parts SO_2 per million, and of these a single one reached 7.1 parts of SO_2 per million. Within the city of Benicia itself no one of 2,841 determinations showed a concentration as high as 2.5 parts per million, whereas over 99 per cent showed less than 1 part per million.

If under these circumstances the prevailing concentrations produce so small a degree of nuisance, it is certain that there would exist no nuisance caused by the odor of the smoke when considered on the basis of the determined facts relative to the sensitiveness of man to sulphur dioxide.

It may be contended that if the concentration was found at one time to be as high as 7.1 parts of SO_2 per million parts of air, the same condition would recur many times during the so-called "closed season," due to the smelter company designedly increasing its capacity and in consequence its output of sulphur dioxide.

As a matter of fact, this high concentration was found under the most adverse wind conditions and with nearly a maximum output of sulphur dioxide from the plant (80 tons per 24 hours). The maximum concentration found in the city limits of Benicia was 2.4 parts of SO_2 per million parts of air, an amount below the limit of the sense of smell of the average person. During any other wind conditions than those of light west winds the concentration of sulphur dioxide in the atmosphere of the smoke zone did not exceed 1.25 parts per million parts of air. This is a point at which even the supposed supersensitive inhabitants of the smoke zone could not detect its presence.

In the light of the data collected by the commission the probability of the recurrence of 7.1 parts of SO_2 per million parts of air in the atmosphere of the smoke zone would be as 1 is to 4456, if the smelter ran at its maximum capacity during the entire season. It is extremely improbable that such a condition would ever exist, and it would appear that the possibility of a recurrence of 7.1 parts SO_2 per million parts of air could be dismissed from any consideration in so far as the odor from the smoke is concerned. The conditions that actually do exist at the present time, and have existed during the investigations of the commission, have been accurately determined.

In the opinion of the commission the average content of sulphur dioxide in the atmosphere of the smoke zone is so low as to preclude the possibility of the existence of a continuous nuisance, which would manifest itself by an objectionable odor or by its effect upon the throat and lungs of human beings or of domestic animals. The commission is of the opinion that the occasional higher concentrations of sulphur dioxide which occur in the atmosphere of the smoke zone are so few in number and so low in sulphur dioxide that no nuisance other than a rapidly transient one is caused by them, which manifests itself by an objectionable odor or by its effect upon the mucous membrane linings of the throat and lungs of human beings or of domestic animals.

There have been 21 occasions, none of which endured for more than 25 minutes, all of which in the aggregate lasted only 250 minutes, during the period of the field tests when extraordinarily sensitive persons could have smelled the smoke from the Selby smelter, and thereby could have been subjected to a nuisance. At the worst this means that the nuisance would have been endured for one 25-minute period in every seven days during this time. Otherwise interpreted, it means that had the visitations been of uniform duration, the odor could not have persisted for more than 12 minutes once in every seven days. The commission is of the opinion that this does not constitute a nuisance within any reasonable construction which can be placed upon the meaning of the word as ordinarily used or as used in the injunction decree or in the stipulation.

Of the remaining 3,748 determinations made in the smoke zone, no figures were obtained higher than 1.25 parts SO_2 per million parts of air. This, as before noted, is below the limit of sensitiveness of the supposed supersensitive residents of the smoke zone, and is so low that none of the 60 subjects of the experiments, before referred to, could detect the presence of anything abnormal in the atmosphere breathed by them. It must be assumed then that this amount is below the limit of sensitiveness of man. As a consequence, such an amount could not be productive of a nuisance through its odor or through its effect on the throat and lungs.

THE OCCURRENCE OF SULPHUR DIOXIDE IN OTHER PLACES.

In order that the commission might be able to draw proper conclusions from the data relating to the composition of the atmosphere of the smoke zone, it was found necessary to collect data in atmospheres that are not contaminated by smelter smoke, but do contain determinable quantities of sulphur dioxide. For this purpose the automobile laboratory was used. Data were collected showing the

content of sulphur dioxide in the atmosphere of San Francisco, Oakland, Berkeley, Richmond, San Pablo, Tormey, Crockett, Martinez, and Avon. The two last-named places are in the area over which smoke from the Mountain Copper Co. smelter, at Suisun Point, blows at certain times. Tormey and Crockett are within the area sometimes covered by the Selby smelter smoke in Contra Costa County.

As will be seen from the figures obtained in San Francisco, Oakland, and Berkeley,[a] sulphur dioxide exists in atmospheres which are not contaminated by smelter smoke, there being no smelters or works of similar character in either of the three places. The source of this sulphur dioxide is the various manufacturing plants in the cities mentioned. It originates in the sulphur that exists in the fuel used. Both coal and oil contain considerable sulphur, which in the burning of the fuel is changed to sulphur dioxide and is given off with the smoke created. A few industries generate additional amounts of sulphur dioxide in the region named.

The composition of the atmosphere in and around Richmond and San Pablo is influenced by the smoke discharged from the oil refinery of the Standard Oil Co. which is situated at Point Richmond. No investigations have been made by the commission as to the quantity of sulphur dioxide eliminated by this plant, but the sulphur dioxide content of the atmosphere of these places was desired and obtained for purposes of comparison.

Comparing the sulphur dioxide content of the Selby smoke zone with that found in other localities around San Francisco Bay it is noted that the air along the ocean beach in San Francisco contains no measurable quantity of sulphur dioxide, whereas the air within the city, on calm mornings, reaches nearly 2 parts SO_2 per million parts of air. To be exact, 1.8 parts SO_2 per million parts of air was the highest amount found in the city in 173 determinations. The average of all the determinations made in San Francisco was 0.3 part SO_2 per million parts of air, which average is slightly higher than that found in the Selby smoke zone. It is to be noted, however, that the figures for San Francisco were not as extensive as for the smoke zone and while the average shows higher it does not necessarily mean that the actual average composition of the San Francisco air is higher in sulphur dioxide than the air of the smoke zone. It is probable that owing to the high winds prevalent in San Francisco during the late morning and early afternoon the industrial smoke which is constantly being given off in the city is much more widely disseminated than the Selby smoke so that the average of tests taken through the day would be less than those taken similarly in the smoke

[a] Report of A. E. Wells.

zone. It is quite within the bounds of possibility and indeed it is quite probable that when samples are taken under wind conditions that are properly comparable for the two areas, the average of the samples taken in San Francisco would be higher than those taken in the Selby smelter smoke zone, although the latter would probably show many more puffs or higher maximum figures than those taken in San Francisco. While the above is more or less speculative it is apparent from the data collected that the air of the smoke zone differs very slightly from that of the business and manufacturing center of San Francisco in its average content of sulphur dioxide.

The air of Oakland and Berkeley, owing to the less number of industrial plants and the influence of different wind conditions, contains on the average slightly less sulphur dioxide than that of the smoke zone or of San Francisco. The conditions are such that the average of the determinations more nearly represents the actual average conditions of the atmosphere than does the average of the determinations in either of the other areas. In these cities no amount above 1 part SO_2 per million parts of air was found in 148 determinations. The detailed tests show a closer agreement to the average of the results; but few determinations approaching the maximum figure obtained.

The determinations made in and about the city of Richmond and at San Pablo should properly be regarded as belonging to one area. The determinations made in Richmond, contiguous to the Standard Oil refinery, show an average of 1.10 parts of SO_2 per million parts of air. Segregating these tests into those made when the refinery smoke was in the vicinity of the sampling place and when the refinery smoke was not in the immediate vicinity shows for the first conditions an average of 1.95 parts SO_2 per million of air and for the second an average of 0.4 part SO_2 per million parts of air. These figures are much higher than the average for the smoke zone or for the other places considered. Even with an average of 0.4 part SO_2 per million of air, with conditions that made for many more puffs of higher concentration than was usually found in the smoke zone, there seems to be small or no complaint by residents of the area that the smoke from the refinery is considered a nuisance.

The sulphur dioxide content of the atmosphere of the country immediately surrounding the smelter at Suisun Point, in the neighborhood of Martinez, has also been studied. A series of 168 determinations was made when the wind direction was such as to blow the smoke from the smelter over the area. These figures show an average content of 0.23 part SO_2 per million parts of air, with a maximum for one test, of 1.7 parts SO_2 per million parts of air. It will be noted that this average is slightly higher than that in the Selby smoke zone, but the maximum concentration found is not nearly so high. For-

tunately for the smelter, situated at this point, the prevailing winds (these same winds also blow over the Selby smoke zone) blow the smoke from the plant over an extensive area of water, Suisun Bay, so that no urban community or agricultural area is affected by the smoke.

In general summary the comparison of the sulphur dioxide content of the atmosphere of the Selby smoke zone with the sulphur dioxide concentration of the atmosphere in other areas around San Francisco Bay and its tributary waters is highly favorable to the Selby smoke zone as to the average amount of sulphur dioxide present. The Selby smoke zone has, however, higher concentrations for short intervals than any of the other areas investigated. The other areas have a more constant higher concentration of sulphur dioxide in the atmosphere than the Selby smoke zone.

CONCLUSIONS.

A careful consideration of all of the data collected concerning the occurrence of sulphur dioxide in the atmosphere in the smoke zone and other places establishes the conclusion that the Selby smelter by the emission into the atmosphere of sulphur dioxide from its plant does not maintain a nuisance in the southern portion of Solano County, Cal., as referred to an objectionable odor or disturbing physiological effects upon the mucous membrane linings of the throat and lungs of human beings and domestic animals.

THE EFFECT OF SULPHUR DIOXIDE ON MAN.

In order to determine the extent to which the invisible part of the Selby smelter smoke may become a nuisance through the physiological effect its content of sulphur dioxide exerts upon man by disturbance of the normal functioning of the respiratory organs or disagreeably affecting the olfactory organs, the commission undertook an investigation to determine the sensitiveness of various persons to sulphur dioxide. It has already been shown that sulphur dioxide is the only gas discharged into the atmosphere through the stacks of the Selby smelter that has an odor or can possibly be present in sufficient amount to produce any effect upon the throat and lungs when it is diluted by the air into which the smoke is discharged.

In the conduct of this investigation [a] 60 subjects were experimented with. Some of the subjects were observed through more than one experiment, so that a total of 85 experiments were recorded. Thirty-two of the subjects were persons who were thoroughly familiar with the odor and general characteristics of sulphur dioxide, and 28 were only sufficiently familiar with the gas to be able to identify

[a] See "Tests to determine the sensibility of man to sulphur dioxide at high dilution," p. 169.

it as "like sulphur matches when they burn," or some similar method of comparison. Those thoroughly familiar with the gas were technically trained men or men who had worked in plants where sulphur dioxide is generated or is used; they were for the most part chemists, engineers, and smelter men. Those who were unfamiliar with the gas were the average intelligent citizens, sometimes capable of accurate description of the sensations they experienced under the tests and sometimes not; they knew the gas only as something which had a "sulphur smell."

Sulphur dioxide (SO_2) is a colorless gas of characteristic pungent odor and acid taste. It is 2.21 times heavier than air, but mixes readily with it in all proportions, and once mixed does not, contrary to popular belief, again separate. In its concentrated form it produces marked physiological disturbances in all animal and vegetable organisms with which it comes in contact. It dissolves to a limited extent in water and has the property of combining with oxygen under proper conditions to form sulphur trioxide (SO_3). Sulphur trioxide combines very readily with water to form sulphuric acid.

Of those subjects who were acquainted with the gas and were trained to observe and report their observations correctly, none could detect the presence of the gas when it was breathed in concentrations of 1 part SO_2 per million parts of air. When the concentration reached 2 parts SO_2 per million, 13 of these subjects suspected the presence of something foreign in the air being breathed but could not identify the substance, while 2 of the 32 thought they could identify the presence of the gas by their sense of taste, although they could not smell it. With 3 parts SO_2 per million in the atmosphere they were breathing 26 of the subjects identified an acid gas as being present, and 6 could detect nothing other than a foreign substance in the atmosphere. Of the 26 who could detect an acid gas, 21 identified it as sulphur dioxide with more or less positiveness, while 5 were doubtful of its identity. At 4 parts SO_2 per million parts of air all but 2 of the 32 subjects were able to detect and positively identify the gas as sulphur dioxide. The two exceptions were men who had become more or less immune to the action of the gas from working in smelters where the concentration is at times very high. At 5 parts SO_2 per million parts of air all subjects but 1, who was especially insensitive, were able to detect the gas. At 8 parts SO_2 per million all subjects, except the above mentioned one, could identify the gas as sulphur dioxide.

This would seem to indicate that persons who are thoroughly acquainted with the properties of sulphur dioxide, through study of or experience with the gas itself, can usually detect its presence in the atmosphere and identify the gas either by the sense of taste or smell when its concentration is about 4 parts per million or more.

Approximately three-fourths of such persons are able to detect and identify the gas when its concentration is 3 parts per million, while about 40 per cent are conscious that a foreign substance is in the atmosphere when the concentration is 2 parts SO_2 per million or more. In concentrations of less than 2 parts SO_2 per million, even persons thoroughly familiar with the properties of sulphur dioxide are unable to detect the presence of any foreign substance either by the sense of smell or the sense of taste.

Of those subjects who were unacquainted with the properties of sulphur dioxide and whose training, in so far as ability to observe and record their observations is concerned, had been that of the average person, none could detect anything in an atmosphere containing 1 part SO_2 per million parts of air. This agrees with the observations of the "trained" subjects. At a concentration of 2 parts SO_2 per million, 2 of these persons detected a foreign smell in the atmosphere they were breathing but could not describe it. With 3 parts of SO_2 per million, 4 subjects "smelled something," and 6 smelled "burning sulphur," while 18 "didn't smell anything." When the atmosphere contained 4 parts SO_2 per million, 10 of the "untrained" subjects smelled "burning sulphur"; 4 "smelled something," and 14 did not note any sensation different from that experienced in breathing the ordinary air. With a concentration of 5 parts SO_2 per million, all of the "untrained" subjects except 6 "smelled something" or "smelled burning sulphur." At 12 parts SO_2 per million, all of the subjects could identify the gas as that of burning sulphur.

This would would seem to indicate that the average citizen, not technically trained, can usually detect the presence of sulphur dioxide in the atmosphere and can identify it either by sense of taste or smell when its concentration is 5 parts SO_2 per million parts of air or more. One-half of such persons are able to detect the presence of the gas and some of them can identify it, when the atmosphere contains 4 parts SO_2 per million. When the atmosphere contains 3 parts SO_2 per million, 65 per cent of the average citizens fail to record any unusual sensations when breathing it, whereas only 217 persons in every thousand would experience the feeling of breathing an atmosphere contaminated with "smell of burning sulphur." When the concentration is 2 parts SO_2 per million, only the most sensitive, 71 in every thousand, can detect a foreign odor; and below that concentration none can detect any foreign odor whatever.

Consideration of the data from all points of view indicates that a proper conclusion will be drawn from this investigation if it is stated that the average citizen is conscious of pollution of the atmosphere by sulphur dioxide when its concentration is approximately 3.5 parts per million parts of air; and the "trained" person is conscious

of such pollution when the concentration is approximately 2.5 parts SO_2 per million parts of air.

In order to positively establish the minimum concentration of sulphur dioxide that would be considered a nuisance to all persons, it would be necessary to experiment with a much larger number of subjects. The time at the disposal of the commission did not permit of this. It was found as a result of the work done in this direction that the elements of psychology and personal idiosyncrasy entered into the matter to a great extent. The symptoms recorded by the various subjects, both "trained" and "untrained," were very dissimilar. No agreement was found between the ideas expressed as to what concentration was a nuisance. Without exception, however, all subjects considered that the point of concentration at which they could just detect a foreign substance or at which they were just conscious that there was something foreign in the atmosphere, was not a nuisance.

The commission is of the opinion, therefore, that in order that the smoke from the Selby smelter shall produce a nuisance in the smoke zone, sulphur dioxide must be discharged from the smelter in such an amount that as the smoke blows over the smoke zone the concentration of sulphur dioxide in the atmosphere of the smoke zone must be 3 parts per million or more. This figure is the mean of those recorded from the "trained" and "untrained" subjects, and refers solely to a nuisance brought about by the presence of a disagreeable or offensive odor.

The concentration of sulphur dioxide that is necessary for the production of injury to plants is a subject that can not be sharply delimited. This phase of the question will be discussed later.

THE EFFECT OF SULPHUR DIOXIDE ON GROWING BARLEY.

The commission is of the opinion that the word "nuisance," as used by the court in the injunction decree and in the stipulation under which the commission was brought into existence, embraces within its meaning any injury which may be done to growing crops or cultivated or forage plants.

Within the smoke zone the commission's investigations relative to the composition of the atmosphere have demonstrated the fact that sulphur dioxide in measurable amount is frequently present in the atmosphere of the smoke zone, and have also shown that the greater part of this sulphur dioxide is directly due to the smoke from the Selby smelter. Furthermore, it is well known that sulphur dioxide has the property of injuring plant growth under certain conditions.

Investigations recorded in the literature covering this subject show that the concentrations of sulphur dioxide required to do injury to

plants as stated by the individual investigators varies between 1 part SO_2 per million parts of air and 40 parts SO_2 per million parts of air. The concentrations required are dependent upon the kind of plant under experimentation, the method of fumigation, and many other conditions. A detailed discussion of these various conditions would lead to interminable lengths, and no generalized conclusion can be drawn from the work previously reported which can be set down in definitely delimiting figures. Comparatively few investigators have worked upon grain crops, although the various grains are known to be very sensitive to sulphur dioxide. As near as can be judged, these investigations show that a concentration of approximately 10 parts SO_2 per million parts of air is necessary to produce injury on growing grain.

Owing to the rather wide divergences in the conclusions of the various investigators and to the fact that in the Selby smoke zone, where a very low average content of sulphur dioxide exists in the atmosphere, distinct injury was noted to some of the most sensitive plants, it seemed essential that further data be collected to throw further light on the question of sulphur dioxide injury to plants growing in the area.

In the opinion of the commission one very grave error which appears in all of the experimental work of which the commission has any knowledge is the absence of conditions of fumigation that approach those existing when plants are fumigated by smelter smoke in the open field. Most, if not all, of the previous investigators make the fumigation by admitting to a closed container (cabinet or "smoke-house") definite quantities of sulphur dioxide. These quantities are so calculated as to produce the desired concentration in the air which fills the container when mixed with the air of the container by some mechanical means, such as a fan. Although this method no doubt produces the calculated mixture or concentration during the very first portion of the fumigation, it is evident that if the plants are injured by the sulphur dioxide through its absorption by the respiratory system of the plant (the method whereby injury is generally conceded to take place) the concentration of the sulphur dioxide is rapidly lowered as this absorption proceeds, to say nothing of the other influences present, such as soil and the walls of the container and the number of plants present, which are all active in reducing the concentration of the gas. Thus the plant is not subjected to a uniform concentration of sulphur dioxide during the fumigation.

Another serious error, which is the direct result of the method of fumigation described above, is that the number of fumigations to which the contents of the cabinet have been subjected, without regard to the length of time each fumigation has proceeded, or to the number

of plants contained in the cabinet, have been taken as measuring the amount of sulphur dioxide that produces a given amount of injury.

It would appear, therefore, that such methods of experimentation do not simulate field conditions of fumigation by smelter smoke nor would the data obtained from such experimental work be of great value in judging what concentrations of sulphur dioxide were necessary to produce a given amount of injury.

In the work undertaken by the commission to determine the effects of sulphur dioxide on plants it was deemed inadvisable to attempt experimentation with a variety of plants because of the limited time at the disposal of the commission for this work and because of the expense attendant upon a complete investigation of the subject. Accordingly all the energies of the commission were bent toward a complete investigation of one kind of plant. The plant chosen was barley. The choice was made for two reasons—barley is a commonly grown crop of the smoke zone, it being grown both for hay and for grain, and it is one of the most sensitive, if not the most sensitive, of the cultivated plants.

The experiments were planned in such a way as to use an actually cultivated field of barley, cared for in the manner generally practiced in the smoke zone, which was located just without the smoke zone in an area which is seldom, if ever, contaminated by smelter smoke. Analyses of the atmosphere in the neighborhood of the experimental field established fully and positively that the normal air of the field contained indeterminable amounts of sulphur dioxide; that is, less than 0.2 parts SO_2 per million parts of air. The field had been poorly prepared for the seed and the seed had been carelessly sown and indifferently attended after sowing. However, a fairly good stand of plants was in evidence as soon as the seeds sprouted and the blades appeared above the ground.

It was arranged to subject the experimental plats, which were about 4 feet wide by 20 feet long, to air containing varying amounts of sulphur dioxide, which air would continually surround the plants and through constant movement would be of uniform concentration during the fumigation, irrespective of the length of time of the fumigation. This condition was brought about by covering the plats with a cabinet constructed of a wooden frame and sheet celluloid, and passing air, previously mixed with known amounts of sulphur dioxide, through the cabinet at a uniform rate.

The amount of air passed through the cabinet was sufficient to produce a small excess pressure within the cabinet and thus obviate the possibility of the outside air gaining access to the cabinet and thus diluting the fumigating mixture. At the same time the passing mixture did not have sufficient velocity to agitate or disturb the

plants to a degree more than that caused by a gentle breeze blowing over them.

In order to check the concentration of the fumigating atmosphere analyses were made of the incoming and outgoing air mixture. The early experiments showed that there was a considerable loss of sulphur dioxide during the passage of the mixture through the cabinet. In subsequent experiments the loss was overcome by means of an improved mechanical arrangement for the delivery of the air mixture. In the detailed report of this work [a] the reasons for this loss of sulphur dioxide are shown to be absorption by the plant, absorption by the soil, absorption by the moisture on the plants and absorption on the walls of the cabinet. The bettered mechanical delivery supplied the air mixture at such a rate that the losses were distributed through a larger volume of air and consequently made the passing air mixture more nearly uniform throughout the cabinet.

The experiments were planned to furnish information upon the following points: First, the amount of visible injury caused by subjecting growing plants to definite concentrations of sulphur dioxide acting during definite lengths of time; second, the effect such injury has upon the total growth or ultimate yield of the crop, and the fertility of the seed; and, third, the existence of so-called "invisible injury" and the extent to which this occurs.

The investigation originally planned included the experimental fumigation of 106 plats at the station near the smoke zone.[b] The results obtained by the early experiments were so at variance with those reported by previous investigators that it was deemed advisable to duplicate the work in another part of the State. Through the courtesy of Dean Hunt of the College of Agriculture and Dean Van Norman of the university farm, permission was obtained to establish a station at the University of California farm at Davis. This set of experiments covered the fumigation of 35 plats. The data collected at each station have been kept separately and the two sets compare very favorably as duplicate work. It was found possible to duplicate any given result obtained at one station by the same conditions applied at the other station.

There are three factors that vitally influence the amount of injury that can be produced by sulphur dioxide. These three factors are: First, concentration of the sulphur dioxide; second, length of time of the application of the atmosphere containing the sulphur dioxide; and, third, the quantity of moisture or water vapor present in the atmosphere during the application of the fumigating mixture. The effect of light, although distinct, is of minor importance.

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[a] "Experiments to determine the effect of highly diluted sulphur dioxide upon a growing grain crop," by A. E. Wells (p. 213).

[b] For location see page 214 of this report.

It is obvious that high concentrations under otherwise similar conditions will produce greater injury than low concentrations, but owing to the variability of the field conditions it is impossible to say, without fixing these variables, that a given concentration will produce a given result.

The investigation developed the fact that, next to the concentration, the time during which the plants are exposed is the chief element in the causation of injury. This result seems a priori obvious. It was further found that the application of a given mixture of air and sulphur dioxide of definite humidity for a given period of time produced the same results if the time of fumigation was applied through a continuous treatment or if the same was applied within short intervals. Thus 5 parts SO_2 per million with a humidity of 40 applied for 1 hour continuously produces very acute injury of what is described in the detailed report as "concentrated" or "killback" type; and if applied for 10 minutes at intervals of 1 hour for 6 consecutive hours practically the same amount of injury is produced. However, when the interval between fumigations is increased the same concentration of sulphur dioxide under the same humidity conditions applied for 10 minutes during each of 6 consecutive days produces much less injury, or the "mottled" type.

It was conclusively shown by the investigation that the quantity of water vapor present in the atmosphere (humidity) is a strong determinative factor in the production of injury. Given concentrations in a dry atmosphere for the same periods of time did not produce as extensive injury as did the same concentrations in a moist atmosphere, although the work was not extended sufficiently in this direction to establish a relationship of a quantitative nature relative to humidity.

The experiments show that visible injury can be produced on barley under innumerable concentrations and conditions of humidity and time. The point at which no injury can be produced by a sufficient time of fumigation with very low concentrations and sufficient humidity could not be established. It is probable that if continued long enough very small concentrations of sulphur dioxide would produce a visible injury. It is believed that with a maximum of humidity (80 to 100 per cent of relative humidity) and a continuously applied atmosphere containing 0.5 parts SO_2 per million slight visible injury would result to barley plants before they had reached maturity. Under field conditions, however, no such conditions of humidity are approached during the entire period of growth of a field of barley. Nor is any area in the smoke zone continuously bathed with air containing anywhere near 0.5 parts SO_2 per million parts of air. Injury may be done under any number of sets of circumstances which are not impossible of occurrence within the

Selby smoke zone, but are highly improbable of occurrence. The best that can be done in the matter of statement of the liability of damage being produced in the smoke zone is to consider the probability of any set of conditions occurring within the zone.

A consideration of all of the data collected in the investigation leads the commission to the belief that a fumigation of barley with an atmosphere containing 20 parts SO_2 per million parts of air if applied for 15 minutes under the average conditions of humidity of the smoke zone will produce very acute injury of the "kill-back" type. Under the same humidity conditions 10 parts SO_2 per million will produce the same amount of injury in 30 minutes, while a like amount of injury will be caused by 5 parts SO_2 per million persisting for an hour with the same humidity conditions.

At no time within a period of 8 months was the concentration of sulphur dioxide in the smoke zone found to be as high as 10 parts per million of air. It is doubtful whether such a condition has ever existed in the smoke zone, and unless the smelter increases decidedly in its capacity (a subject which will be separately considered) such a concentration persisting for the period of time required to do damage—that is, one-half hour—would be, in the opinion of the commission, very unlikely.

The records of Mr. Wells show that on one day at station 2 a concentration of sulphur dioxide between 5 and 7 parts per million persisted for a period of 35 minutes, and that a rough average of 2.5 parts per million prevailed for 4 out of the 6 hours of the day during which tests were made. Such conditions have been shown to produce distinct injury to growing barley, and if repeated a sufficient number of times may seriously diminish the crop yield.

However, it is to be noted, first, that station 2 is so situated on the high hills above the Straits of Carquinez as to receive a maximum effect from the smelter when the wind is blowing toward the smoke zone; second, that the atmospheric conditions at the time were such as to cause the smoke stream from the smelter to drift slowly past the station; third, that on this day the smelter, at the request of the commission, was emitting a maximum amount of sulphur dioxide; fourth, that at no other time did those conditions recur during the period of the commission's investigations; and, fifth, that, except the slopes of the hills facing Carquinez Straits, there are no areas within the smoke zone likely to be bathed by such concentrations of sulphur dioxide.

It is therefore obvious that the probability of economic damage to growing crops, even in the more exposed parts of the smoke zone, is remote. The probability of economic damage in the less exposed areas is still more remote, if not absolutely nil.

Passing, now, to a consideration of the injury that might be done by concentrations of sulphur dioxide as high as 2 parts per million, which were found to exist in the area on 21 occasions, what are the probabilities?

It is a fact that under certain conditions considerable visible injury and even economic damage can be produced by 2 parts SO_2 per million. If such concentration is applied continuously for 4 hours under average humidity conditions, or for 10 minutes daily during the entire growing season, some visible injury is produced. The effect of such visible injury on the ultimate yield is, however, very slight.

The data concerning the sulphur dioxide content of the atmosphere show that a concentration of 2 parts SO_2 per million never endured for a period of over 30 minutes, and that the total time such concentrations existed was not greater than 3½ hours during the entire period. Although it is true that an application of 2 parts SO_2 per million for one-half hour under especially unfavorable conditions produces slight injury, such slight injury does not reduce the yield and has no economic importance.

It is the opinion of the commission that the probability of the concentrations of SO_2 in the atmosphere being at 2 parts per million for a sufficiently long-time fumigation, or in sufficient number of repeated short-time fumigations to produce visible injury, is very remote.

With concentrations of 1 part SO_2 per million it was found that although a slight visible injury resulted from two 7-hour fumigations, it was also found that six 7-hour fumigations, or ninety 10-minute fumigations, produced no determinable decrease in yield.

As the total time during the whole period that the concentration in the area was found to be 1 part SO_2 per million or more was only 1,220 minutes, and this total time was divided between 17 days in 8 months, it is considered highly improbable that any economic damage to growing crops could result in the smoke zone by the existence of such concentration.

Furthermore, a consideration of the length of time of application and the number of applications required to produce any visible injury with 0.5 part SO_2 per million, together with the longest period of time such concentration was found to be present continuously, or the number of times it was found for shorter periods, leads the commission to conclude that there is no possibility of economic damage resulting in the area from that low concentration.

Therefore it is the opinion of the commission that the sulphur dioxide which is emitted by the Selby smelter and is carried by the winds over the smoke zone is not a nuisance with reference to its action on vegetation by the reduction of yields of crops when the maximum output of sulphur from the plant does not exceed 40 tons

per day. It is the opinion of the commission that at any time during the operation of the smelter wind conditions may occasionally obtain whereby slight visible injury may be done to the most susceptible plants in the more exposed areas of the smoke zone by sulphur dioxide existing in the smoke of the Selby smelter; but that this slight visible injury is of no economic importance for the reason that the yield of crops is not diminished by such slight visible injury, nor is the vegetation so injured detrimental to the health of stock.

If with slight or even heavy visible injury there results no economic damage, it is difficult to see how any invisible injury which may result can be productive of economic damage as expressed in decreased yields of crops and decrease in the fertility of the seeds.

Finally, attention is called to the fact that the commission's plant pathologists, Dr. Blankinship and Prof. Jones, each after careful and repeated examination of the whole area included within the smoke zone, have reported a few instances of sulphur dioxide injury—in such slight amount, however, as to be economically of no significance whatever. Both these experts agree that during the period of the commission's investigations no economic damage was done to growing crops by sulphur dioxide emanating from the Selby smelter.

THE EFFECT OF SULPHUR DIOXIDE ON MATERIALS MADE OF IRON.

One of the common sources of complaint within the smoke zone has been that wire screens and barbed wire, which is put in use in the area, deteriorates very rapidly on account of the presence of the smoke from the smelter. There is no doubt as to the fact that these materials do deteriorate rapidly in the smoke zone, but such deterioration is not due, in the opinion of the commission, to the action of the sulphur dioxide which exists in the atmosphere so much as to the heavy fogs existing in the area. These fogs carry considerable water; and the so-called salt air, in combination with the water, cause much corrosion of iron and steel, particularly the latter. This fact, when considered in the light of the modern method of manufacture of wire screen and barbed wire, readily explains why these materials deteriorate more rapidly than they used to. The past 15 years have been productive of a great increase in the amount of steel used in the manufacture of wire and wire goods and a great decrease in the amount of iron wire and wire goods produced. Steel deteriorates when subjected to intermittent moistening much more rapidly than does iron. This corrosion is a condition noted all over the country and is particularly evidenced in regions of heavy fogs and heavy dews far away from smelters.

In the opinion of the commission the sulphur dioxide of the smoke from the Selby smelter, although it probably does exert a slight

effect when it is present in the atmosphere of the smoke zone, in the deterioration of iron and steel through corrosion is of so slight importance as to be worthy of no consideration in connection with the existence of a nuisance which may be maintained by the Selby smelter through its smoke.

PLANT PATHOLOGICAL SURVEY OF THE SMOKE ZONE.

For the determination of the conditions existing in the smoke zone as regards the crops of various kinds and the many kinds of plant life found therein, the commission engaged the services of Dr. J. W. Blankinship and Prof. W. W. Jones, plant pathologists of a high degree of training and of extensive experience in the study of plants in relation to smelter-smoke injury. Each was commissioned to make a complete plant pathological survey of the area, reporting all abnormal conditions which exist, and to trace wherever possible the actual cause of such conditions. The investigations of these experts were carried on independently, each being free to draw such conclusions as he deemed the proper ones relative to the general conditions and to such specific conditions as were covered by his work.

In general summary, the two experts are agreed that the Selby smoke zone, in comparison with areas of the same size in the Western States, shows a larger number of plant diseases and other adverse influences which affect the health of plants. So far as could be discovered, no attempt is made by the farmers of the smoke zone to combat or cure these diseases; whereas in most other sections some effort is made to rid the area of such conditions. No disease was found to be prevalent in the Selby smoke zone which is not also found in other areas. In other words, the smoke zone contains no typical or specific diseases which might find within a smoke zone the conditions favorable for their growth.

Many diseases, such as root rot and various fungus diseases, which prevent a normal, not to mention maximum, development of the trees, exist in the smoke zone. These plant diseases, taken in conjunction with a general lack of care of the trees, with poor cultivation and improper preparation of the soil, and the rather low annual rainfall of the area, do not make for great growth in the trees nor for much productiveness. The grain crops are, for the most part, infested with fungus diseases of various kinds and of more or less virulence. The most prevalent disease of this character is known as Helminthosporium. A bacterial blight is also very common in the area. These conditions, together with poor methods of cultivation and preparation of the seed bed, very markedly decrease the yield of barley, wheat, and oats by depriving the plant of its proper nourishment at its critical stage of growth. The appearance of the

leaves of the affected plants are in many instances similar to that of leaves damaged by sulphur dioxide, with the result that the two are often confused by the untrained observer.

The deplorable condition of the numerous Monterey cypress in the area is shown by Dr. Blankinship to be due to the effects of any one or more of a number of diseases and pests and not at all to smelter smoke.

The condition which obtains in relation to the fruit trees of the region is caused by the ravages of diseases such as "shot-hole disease," "wood rot," "pear blight," "crown gall," "gummosis," "leaf curl," and "mildew" and the inroads of many kinds of insects, acting in conjunction with poor cultivation and a lack of effort to combat them. Smelter smoke as it exists in the area does not influence the growth of fruit trees for good or for ill. The same can be said of the shade and ornamental trees of the area. In these latter varieties drought and grass fires have caused a lessening of the vitality of the trees and, when not killing them outright, have laid the trees open to easy attack by diseases and insect pests.

Both investigators, during their observations, discovered evidence of slight smelter-smoke injury to the native herbiage and to barley and oat plants. In no case was the damage sufficiently in evidence to be noticed except by an expert who was searching for it. Along the shore of the area and on the high bluffs directly across from the smelter and on the Dos Reis place this small amount of injury was noted shortly after a rain, but in no case was it, in the opinion of the experts, sufficiently marked to be of any economic importance. The injury was not general in any sense but confined to a few plants widely scattered and would not be productive of the amount of damage that would be done by one head of stock breaking into a grain field and grazing for one minute. Injury due to sulphur dioxide, even in such slight degree, was not found in what can be described as the real agricultural centers of the smoke zone. No evidence of sulphur dioxide injury was noted by either investigator on any of the trees of the area nor on the shrubs or vines. Every pathological condition of the vegetation of the area is accounted for either by disease, insect pests, cultural conditions, drought, or untoward conditions other than sulphur dioxide.

The commonly occurring sootlike deposit on the trees of the smoke zone, which is believed by many of the farmers to be deposited from the smoke of the smelter, is clearly shown to be a mold which grows in the honey dew secreted by certain predacious insects which infest the trees. Direct microscopical examination of this sootlike deposit also shows it to be chiefly of organic nature and not of the inorganic nature of the solid particles of smelter smoke.

It is the opinion of the commission that the only conclusion which can be drawn from the work done in the plant pathological survey is that the poor conditions of growth of many kinds of vegetation in the smoke zone are directly traceable to one or more of the following causes: Plant diseases, predacious insects, poor soil, poor cultivation, lack of water, and indifference to all of these conditions by the farmers of the area. None of the conditions existing so far as vegetation is concerned can be attributed to the effects of the smoke from the Selby smelter which blows over the area, known as the smoke zone.

ENTOMOLOGICAL SURVEY OF THE SMOKE ZONE.

For the investigation of insect injury to vegetation in the smoke zone the commission engaged R. W. Doane, professor of entomology of Leland Stanford Junior University, to make an entomological survey of the area. Prof. Doane began his work late in the fall (1913) when most of the predacious insects are lying dormant and at a period when a portion of the damage suffered by the trees during the preceding period of insect activity could be advantageously observed. His investigations extended through the winter and spring months and well into the early summer, so that the seasons of activity of most of the various insects were fully observed.

The investigations of Prof. Doane established the fact that much of the poor condition of the trees and crops of the smoke zone is due to the work of insect pests. He finds that in the large majority of cases no attempt is made by the farmers of the area to combat these insect pests and that the lack of care in this direction is responsible for the remarkable prevalence of them. The indifference of the farmers to these conditions is illustrated by the fact that during his investigations Prof. Doane volunteered to advise certain farmers free of charge as to the proper methods of combatting insects and to supervise their attempts if they would but make the attempt. However, none took advantage of the opportunity to improve the existing conditions.

No less than eight varieties of scale insects were found to occur in sufficient numbers to exert a marked influence for ill on the growth and productiveness of fruit trees and ornamentals. Four varieties of aphis were found to be abundant. The green aphis and the woolly aphis were present in some of the orchards in numbers greater than ever before encountered anywhere by Prof. Doane. Aside from the 12 varieties of insects mentioned above, 13 other varieties were found to be prevalent and doing more or less damage to plants of all kinds.

In some instances the death of trees was traced directly to the activities of insect pests, and in all cases in which trees were found to

be languishing insects have been a contributary cause of their ill condition. Insect pests were found to have inflicted much damage on the ordinary garden truck grown in the district for home consumption, and but little if any effort is made by the growers to stay the ravages of these pests.

One very serious pest was discovered in this entomological survey in conjunction with the work of the plant pathologists, namely, the Hessian fly. This pest has caused immense amounts of damage in various grain-growing areas of the world and its advent in a hitherto untouched region is a circumstance of greatest moment if the area is of agricultural importance.

At the request of the commission and in the hope that the work would prove an object lesson to the farmers and residents of the smoke zone, Prof. Doane directed several spraying experiments to show the people of the smoke zone how to combat insect pests. His experiments showed clearly that the trees treated were in much better condition than the untreated trees, particularly as regards the "sooty deposit" always referred to by the farmers as being due to smelter smoke. At this writing it is too early to determine what effect the object lesson will have. It is to be hoped that the owners of the orchards in the smoke zone will follow the advice of Prof. Doane and make serious efforts to rid their orchards of these pests.

The Selby smoke zone is about at the average of other neglected California farming areas in the matter of the number and prevalence of insect pests. It can not be expected that trees heavily infested with insects, which live upon the sap and juices of the trees, can be productive nor can they be healthy and vigorous. As well expect cattle covered with ticks and other parasites to thrive and be marketable as prime cattle as to expect a fruit tree to produce fine fruit when a large portion of its energy is expended in overcoming the attacks of insect pests.

The commission is of the opinion that the general conclusion to be reached from a consideration of the data collected by the entomological survey is that poor care, as expressed by lack of cultivation, lack of proper pruning, lack of spraying and fumigation with insecticides, and slipshod methods of farming, is mainly responsible for the bad conditions which exist in the Selby smoke zone as to trees, crops, and vegetation in general.

AGRONOMIC AND SOIL SURVEY OF THE SMOKE ZONE.

The preparation of a report on the agronomic conditions of the smoke zone and on the question of the possible contamination of the soil by smelter emanations was given over to Charles F. Shaw, professor of agronomy of the University of California, and Mr. E. E. Free, agronomist and soil expert of San Francisco.

The problems presented to these experts were: First, are the agronomic conditions of the smoke zone such as to permit high agricultural development; second, is there in the smoke zone any soil trouble which is responsible for any poor condition of plant growth which may exist; third, has the soil of the smoke zone been polluted by materials deposited there from smelter smoke; fourth, if such pollution exists is it of economic importance; does it influence adversely the growth of crops or other vegetation.

The findings of Messrs. Shaw and Free show that the soils of the smoke zone can not be regarded as of high quality nor even up to the average of good farming areas. They lack diversity of mineral constituents and are consequently poor in plant-food materials. The soils are shallow and have only small capacity for the storage of water and for the accumulation of humus. The annual rainfall of the areas is low for the requirements of the kind of soil that is found in the area and the careless and poorly thought out methods of agricultural practice that are in vogue do not conserve the rainfall nor do they tend to increase the capacity of the soil for water storage or for the accumulation of humus. The soils do not contain alkali.

The yields of crops in the area are below the average for areas in other sections of the State having a similar climate. The poor quality of the soil and the poor agricultural practices are sufficient to account for the existing bad conditions as to crops and crop yields. No soil trouble exists other than the poor quality of the soil, to which the existing conditions of plant growth can be traced.

In the matter of soil pollution an extensive investigation was conducted. Samples of soil were taken from various parts of the area and subjected to examination to determine the presence of lead and arsenic. If the soil is polluted by emanations from the smelter, these metals are the elements in the smoke that would cause the pollution.

The results of the investigation point to the fact that both arsenic and lead are natural constituents of the soils of the smoke zone and of the country surrounding the smoke zone as far away as 15 miles or more. The amounts of these metals which occur naturally in the soils of the smoke zone are, however, very small. It was found that on the bluffs overlooking the Straits of Carquinez and in the more directly exposed areas there has without doubt been pollution of the soil by the emanations from the smelter. Both lead and arsenic occur here more abundantly than in the soils of the regions of the smoke zone more remote from the smelter. On account of these substances (lead and arsenic) occurring normally in the soil and in variable quantities, it is impossible to say what portion of the lead and arsenic found in the soils was deposited from the smoke from the Selby smelter and what portion occurs normally. It is estimated by these

experts that the amount of these substances which has been added to the soil through the agency of smelter smoke is about the same as is normally present in the soils. What the source of arsenic and lead found in the soils both of the exposed and the unexposed areas may have been is a matter of no particular importance in the present connection because the quantity present is not sufficient to be a factor which would influence the growth of plants for good or for ill. In the opinion of Messrs. Shaw and Free the soils of the smoke zone are not "poisoned" by substances deposited upon the soil from smelter smoke.

To substantiate their conclusions in the matter, Messrs, Shaw and Free submitted their findings and data to Charles B. Lipman, professor of soil chemistry and bacteriology in the University of California, asking his opinion as to the possibility of the stated amounts of arsenic and lead which occur in the soils of the smoke zone having any influence on the growth of plants. Prof. Lipman states emphatically, and bases his statement on the results of his own investigations, that such quantities of arsenic and lead have no adverse influence on the growth of plants, that indeed such small quantities seem rather to stimulate their growth.

Substantiating the opinion of the agronomists is the agronomic record kept by Mr. Ralph W. Brown during the period of the survey. Even casual inspection of this record points strongly to the fact that the agricultural practices of the smoke zone are not good; in fact, they are such that it is small wonder that large yields of crops are not common, and on the whole it is remarkable that the crops yield as well as they do.

Supplementing the agronomic survey, the commission collected data which throw some light on the amount of arsenic and lead which has been deposited from the smoke of the Selby smelter upon the smoke zone. This investigation is detailed in the reports of Mr. Wells [a] and was undertaken in the hope of determining some of the conditions that may have existed in the past.

An attempt was made to measure the deposition of solids from the smoke by catching on glass plates the dust carried in the atmosphere of the area. These tests were made prior to the installation of the bag house for the roaster stack, which clears all of the smoke coming from the plant of its visible element, and are of interest in showing that contamination of the soils and vegetation of the area has undoubtedly taken place in the period which antedates the installation of the bag house.

The amount of dust collected within the time the experiments were carried on proved to be unimportant from the point of view of con-

[a] See pp. 181-188.

tamination of the soil to the point of damage to it. Using the figures obtained as a basis for calculation, it develops that the amount of lead, for example, which would be deposited on the top 2 inches of soil in a year's time would be 0.4 part per million of soil, if all of the area of the smoke zone were evenly covered with dust deposited at the same rate as occurred on the test plate showing the maximum of deposition. According to the investigations of Prof. Lipman, made independently of the commission's work, this amount must be increased 3,000 times before the presence of lead in the soil becomes toxic or injurious to plants or in any way interferes with their growth.

The commission finds that the soil of the smoke zone contains lead and arsenic as natural constituents, and that the operations of the Selby smelter have resulted in slight additions to the quantities of these metals normally present. It also finds that, as at present operated, the smelter smoke contains nothing more than traces of these metals. Finally it finds that the amounts of lead and arsenic in the soils of the smoke zone are so small that they are without effect upon vegetation growing in the smoke zone.

The commission is, therefore, of the opinion that no nuisance exists at the present time as a result of the presence of lead or arsenic in the soil of the smoke zone, nor has one ever existed so far as "poisoning" of the soil is concerned.

VETERINARY SURVEY OF THE SMOKE ZONE.

Dr. C. M. Haring, professor of veterinary science at the college of agriculture, and Dr. Karl F. Meyer, of the department of pathology of the medical school of the University of California, made a careful examination into the conditions in the smoke zone as affecting the health of farm animals.

This veterinary survey included the identification of every horse and the enumeration of all of the other domestic animals within the zone. The work of identification and classification of the animals by the card-index system of cataloguing was done by Mr. William La Grange. The listing of the horses developed the fact that 31 horses out of a total of 308 within the smoke zone were suspected as being of the type known as "roarers." Of these 31 suspects, 12 cases were diagnosed as "roarers" by the veterinarians. Of the remaining 19, 8 were claimed by the owners to be "smeltered," but no evidence was found by the veterinarians to support the claims. Eleven of the 19 cases were suspected by the veterinarians as being "roarers," but 5 of these were necessarily left without further diagnosis because objections were raised by the owners to the veterinarians making any serious and careful study of them. In the remaining 6 cases the evidence obtained was not sufficient to establish a diagnosis.

The condition known as "roaring" in horses is brought about by various circumstances and contributory causes. Among these contributory causes it is known that chronic lead poisoning is very common. In order to determine to what extent the animals, which were under suspicion, were suffering from possible chronic lead or arsenic poisoning, it was necessary to make a complete and systematic study of each one. The unwillingness of certain owners to permit study of suspected animals shows little desire on their part to be instrumental in securing an equitable settlement of the litigation which has heretofore existed, and leads the commission to believe that their cupidity and desire to misrepresent conditions for their own monetary benefit was with them the paramount issue. Despite the reprehensible attitude in declining to permit the veterinarians to examine their animals, these owners were insistent that their horses had been "smeltered." These cases are listed as suspects, because their owners claimed they had been "smeltered." The commission is firmly of the opinion that none of the owners who objected to a study being made of their stock is sufficiently qualified as a veterinarian to diagnose "smeltering," and as a consequence no weight shall be given by the commission to the statements of such owners as to animals having been "smeltered." If the owner honestly believes his animal is injured, there can be no valid reason why he should object to a study for the purpose of establishing the fact.

A complete and systematic study of the conditions of the 12 horses which were suspected by the veterinarians of being "roarers" was made during the course of the survey. Diagnosis of these cases disclosed in every instance that the animal was afflicted with the trouble suspected. Two of the animals were killed and autopsied and the autopsy confirmed the diagnosis. Two of the cases were taken to the university farm at Davis and were operated upon for the correction of the trouble. One case recovered and one case was much improved, but was not sufficiently benefited by the operation to pass as cured.

"Roaring" is brought about directly by the paralysis, either partial or complete, of certain muscles of the throat and neck. This paralysis causes improper functioning of the respiratory organs, so that during exercise or when at rest immediately after exercise the animal breathes with a peculiar roaring sound. The animals seldom succumb to the direct effects of the roaring, but owing to the improper functioning of the respiratory organs they are subject to attacks of pneumonia, which usually ends fatally. Another direct cause of death in "roarers" is the lodgment of food in the lungs owing to the paralyzed condition of the muscles of the throat. Such conditions bring about complications and the animal generally dies of some acute attack on the respiratory organs.

It is known that ingestion of lead with food produces the condition of paralysis above referred to. Other things also cause it, but the proportion of "roarers" is usually greater in the vicinity of industrial plants which give off lead or lead compounds than in areas not so situated.

During the course of the investigations two horses died in the area from pneumonia which was superinduced by the weakened condition of the animals, which condition was undoubtedly due to a paralysis caused by the ingestion of lead with the food. The cases were of long standing, and it is probable that the paralysis has been a long time developing to the point which would produce a "roarer" from the otherwise healthy animal.

In considering the occurrence of "roaring" in the smoke zone the veterinarians have divided the zone into two portions—one, that part which is obviously directly exposed to the smoke from the Selby smelter, and the other the unexposed or less directly exposed section of the smoke zone. Within the obviously exposed area there were enumerated 140 horses. Of this number 12 were positively diagnosed as "roarers." It can be positively stated that the exposed areas of the smoke zone contain 8.5 per cent, at least, of "roarers." This figure is considered high by the veterinarians for the proportion of "roarers" present in average areas. From the fact that 11 additional cases were suspected by the veterinarians and 8 cases were claimed by the owners to have been "smeltered," none of which were fully studied from one cause and another, it is quite certain that the proportion of "roarers" in the entire zone is higher than the above percentage would indicate.

In the opinion of the veterinarians the condition of these "roarers" was due to the effects of the paralysis above referred to, which paralysis was directly brought about by chronic lead poisoning.

It is the opinion of the commission that the smoke from the Selby smelter has in previous years carried lead or lead compounds which have been deposited upon the area, and it must be assumed that at least some of these animals have been injured by lead deposited from smelter smoke. In the opinion of the veterinarians none of the studied cases is of recent origin.

Irrespective of what the conditions have been in the past in regard to the deposition of lead upon the area, such conditions have not obtained since April, 1914, nor will they obtain in the future if present operating conditions continue, as the roaster-stack bag house removes the last visible smoke, and hence eliminates all possibility of subsequent deposition of either lead or arsenic upon the area.

POSSIBILITIES OF LESSENING THE OUTPUT OF SULPHUR DIOXIDE.

As referred to in the fore part of this report the studies conducted at the smelter were productive of a recommendation by the commission October 25, 1913, that apparatus be installed to remove all of the visible portion from the smoke being discharged from the plant. It was believed necessary by the commission, in order that full information might be at hand upon which to base recommendations for the subsequent operation of the smelter in the event that a nusiance was found to exist within the smoke zone, to make certain studies to determine the possibility of eliminating the sulphur dioxide from the smoke of the plant before it is sent into the atmosphere.

These studies were made upon that part of the metallurgical processes of the plant known as "roasting." It was found that, by the introduction of more complete control of the constituent parts of the charges roasted and sintered on the Dwight & Lloyd sintering machines, it was possible to operate the machine in such a way as to drive off at certain points of the machine the greater part of the sulphur contained in the charge in a manner which would easily permit of its subsequent elimination from the discharged smoke. These conditions were also found to produce a product from the charge which was much better adapted for the subsequent metallurgical operations to which the sintered material is subjected, and to that extent, at least, the metallurgical practices of the plant can be improved. The driven-off sulphur, in the form of sulphur dioxide, was found to be susceptible to easy concentration to such percentages of sulphur dioxide as would make it possible, technically, to utilize the gas for the production of either sulphur, sulphuric acid, or liquid sulphur dioxide. The details of the study need not be discussed in this report, but can be left to the report of A. E. Wells.[a]

Although the commission finds that no economic damage is being done by the comparatively small amount of sulphur dioxide now emanating from the plant of the Selby Smelting & Lead Co., it is nevertheless cognizant of the prospect that there will always be objections raised to the discharge of even moderate quantities of sulphur dioxide into the atmosphere of farming and thickly populated regions. The commission shares these objections and entertains a firm conviction that all smelting plants should do their utmost to find ways and means of avoiding the escape of sulphur dioxide into the atmosphere, and that in cases of obvious neglect of

[a] Report of investigations on the gases from Dwight & Lloyd sintering machines at the Selby smelter, pp. 324-337.

duty in this respect the people should take steps to bring the offenders to a realization of their obligations to the community in which they operate. With present conditions in mind and looking confidently forward to a steadily increasing population and growth of the varied industries of this region, the commission recommends that the Selby Smelting & Lead Co. make an earnest effort to reduce the amount of sulphur dioxide now discharging into the atmosphere from its smelter as soon as it is practicable to do so by the production of either sulphur, sulphuric acid, or liquid sulphur dioxide.

CONCLUSIONS AND FINDINGS.

The commission concludes:

1. With respect to the visible element of the smoke from the Selby smelter:

(*a*) That prior to April 1, 1914, a nuisance, measured by the cumulative injury done to certain horses, was maintained in the smoke zone.

(*b*) That the installation of the bag house in connection with the sintering machines of the smelter has resulted in the abatement of this nuisance.

(*c*) That lead and arsenic from the smoke of the Selby smelter was deposited on the soil of the smoke zone during the period of time included between the beginning of operations of the smelter and April 1, 1914, but that the quantity of these metals so deposited was of no economic importance and did not poison the soil or in any way produce a loss or reduction of crops.

(*d*) That the blackened appearance of many trees and plants in the smoke zone, which appearance is believed by many of the residents of the smoke zone to be due to a deposit of lead from the smelter smoke, is in fact not due to such cause. The so-called "lead deposit" results from the growth of a mold within the honeydew secreted by certain insects which infest the trees and plants and contains no lead whatever.

2. With respect to the sulphur dioxide contained in the smoke of the Selby smelter:

(*a*) That the Selby smelter has not maintained a nuisance with respect to producing within the smoke zone a disagreeable or objectionable odor, or with respect to disagreeably or injuriously affecting the throat and lungs of human beings or domestic animals living in the smoke zone.

(*b*) That the rare instances during the investigations of the commission when sulphur dioxide from the Selby smelter was present in the smoke zone in sufficient concentrations to be observed by the residents by the sense of smell do not constitute a nuisance; nor do

these rare visitations prevent the residents of the smoke zone from the peaceful enjoyment of life and property.

(*c*) That the Selby smelter has not maintained a nuisance with respect to economic damage to trees, vines, shrubs, or growing crops of any kind within the smoke zone.

(*d*) That the Selby smelter has not maintained a nuisance with respect to the corrosion of wire screens or barbed wire in use within the smoke zone.

3. With respect to the future operation of the Selby smelter:

(*a*) That so long as the mechanical devices now used at the Selby smelter for clearing the smoke of the plant of its visible element are kept in operation the Selby smelter will not maintain a nuisance with reference to injury to horses or other domestic animals, or with reference to injury to the soil of the smoke zone; nor will a nuisance be maintained by the Selby smelter in these respects so long as the visible element is removed from the smoke by any means, mechanical or otherwise.

(*b*) That the apparatus now installed at the Selby smelter which are used to eliminate the visible element of the smoke are subject to accident and are so constructed as to require occasional cleaning and repairing; and that, for the purpose of cleaning and repairing the apparatus so used, the Selby Smelting & Lead Co. will not maintain a nuisance in the smoke zone if it discharges visible smoke from the blast-furnace stack for a total period of no more than 48 hours in any one month of each calendar year; or if it discharges visible smoke from the roaster stack for a total period of no more than 48 hours in any one month of each calendar year.

(*c*) That during that portion of the year known as the "closed season"—that is, from March 15 to November 15 of each year—the emission of smoke into the atmosphere from the furnace known as the Ropp roaster will be productive of a nuisance in the smoke zone unless the visible element is removed from the smoke before it is discharged into the atmosphere.

(*d*) That so long as the total output of sulphur dioxide which is discharged through all of the stacks of the Selby smelter into the atmosphere is less than 80 tons per day of 24 hours during each hour of which day less than 3⅓ tons of sulphur dioxide are discharged the smelter will not maintain a nuisance with respect to a disagreeable or objectionable odor or with respect to disagreeably or injuriously affecting the throat and lungs of human beings or domestic animals living within the smoke zone; that the smelter will not maintain a nuisance with reference to economic damage to trees, shrubs, vines, or growing crops of any kind growing within the smoke zone; that the smelter will not maintain a nuisance with reference to the corro-

sion of wire screens or barbed wire in use within the smoke zone; and that no nuisance of any kind will be maintained within the smoke zone with respect to sulphur dioxide under the above-stated conditions of operation.

The commission therefore finds, and so makes answer to the requirements of the stipulation, that the Selby Smelting & Lead Co. in the operation of its plant near Vallejo Junction, Contra Costa County, Cal., was, at the time of the organization of the commission, violating the terms of the decree of the injunction issuing from the Superior Court of Solano County, Cal., and was maintaining a nuisance with respect to cumulative injury to certain horses within the area of the southern portion of Solano County heretofore designated as the smoke zone; but that in installing proper apparatus for the elimination of the visible element of the smoke discharged from the plant the said Selby Smelting & Lead Co. has since April 1, 1914, complied in all respects with the terms of the decree of injunction both in letter and in spirit, and has not since that time and up to the present time, November 6, 1914, violated the terms of the said decree or maintained a nuisance in the area of the southern portion of Solano County, Cal., heretofore designated as the smoke zone.

The commission finds and makes known that, by continuing the elimination of the visible element from the smoke discharged into the atmosphere from its plant near Vallejo Junction, Contra Costa County, Cal., and at all times maintaining the total output of sulphur dioxide from said plant at less than 80 tons per day of 24 hours, during each hour of which day less than 3⅓ tons of sulphur dioxide are discharged, during the period of each year covered by the said injunction decree, then the Selby Smelting & Lead Co. will not violate the terms of the said decree of injunction and will not maintain a nuisance within the area of the southern portion of Solano County, Cal., heretofore designated as the smoke zone.

The commission finds and makes known that, by discharging visible smoke from the blast-furnace stack, during the cleaning or repairing of the apparatus by which the visible smoke is eliminated, for a total period of no more than 48 hours in any one month of the period covered by the said decree of injunction; or by discharging visible smoke from the roaster stack, during the cleaning or repairing of the apparatus by which the visible smoke is eliminated, for a total period of no more than 48 hours in any one month of the period covered by the said decree of injunction the Selby Smelting & Lead Co. will not violate the terms of the said decree of injunction and will not maintain a nuisance within the area of the southern portion of Solano County, Cal., heretofore designated as the smoke zone.

The commission finds and makes known that, if the Selby Smelting & Lead Co., as the result of conditions of operation that may arise in the future, desires to use the furnaces known as the Ropp roaster during the period known as the "closed season," then, if the smoke from the said furnace is so treated before it is discharged into the atmosphere as to remove the dust and fume therefrom, the said company will not violate the terms of the said decree of injunction and will not maintain a nuisance within the area of the southern portion of Solano County, Cal., heretofore designated as the smoke zone, during the period covered by the said decree of injunction.

FINANCIAL REPORT.*

By N. M. Porter.

The financial transactions of the commission have been accurately recorded and are herewith submitted. The time covered is from May 1, 1913, to December 1, 1914. The funds received amount to $27,000.

Appended to this report is the statement of the certified public accountant who has audited the books.

The following is a general summary of the costs of the various investigations:

General chemical investigations on composition of atmosphere and conditions at smelter	$11,205.58
Plant pathological survey and fumigation experiments	4,040.22
Agronomic and soil survey	2,516.80
Entomological survey	707.55
Veterinary survey	725.18
Bibliography	454.50
Travel	2,003.92
Office expense	2,421.90
Miscellaneous expense	1,529.39
Equipment	2,317.36
Total	27,922.40

Balance sheet, Selby Smelter Commission, November 30, 1914.

Item.	Debit.	Credit.
Wells Fargo Nevada National Bank	$142.44	.....
Selby Smelting & Lead Co	.....	$21,000.00
Personal services	17,104.86	.....
Office expenses	1,191.90	.....
Equipment	2,317.36	.....
Field expenses	7,308.28	.....
Interest and discount	.....	1.24
Solano County Board of Supervisors	.....	6,000.00
Sales of equipment	.....	1,063.60
Total	28,064.84	28,064.84

* Dated Dec. 1, 1914.

STATEMENT OF PUBLIC ACCOUNTANT.

SAN FRANCISCO, *December 1, 1914.*

Mr. RALPH A. GOULD,
Secretary Selby Smelter Commission,
San Francisco, Cal.

DEAR SIR: In accordance with your request, we have made an audit of the books, accounts, and records of the Selby Smelter Commission from May 23, 1913, to November 30, 1914; have verified the cash account by certificate from the depository; have ascertained that all payments are covered by sufficient vouchers, and

We hereby certify that the attached statement of receipts and disbursements, for the period indicated, agrees with the books and is correct.

Herewith please find Exhibit A, "Statement of receipts and disbursements of Selby Smelter Commission for the period May 23, 1913, to November 30, 1914."

Yours, truly,

HASKINS & SELLS,
Certified Public Accountants.

Selby Smelter Commission—Statement of receipts and disbursements for the period May 23, 1913, to Nov. 30, 1914.

RECEIPTS.

Selby Smelting & Lead Co.		$21,000.00	
Solano County		6,000.00	
Discount		1.24	
Total receipts			$27,001.24

DISBURSEMENTS.

Personal services		$17,104.86	
Field expenses		7,308.28	
Office expenses		1,191.90	
Equipment	$2,317.36		
Less sales	1,063.60		
		1,253.76	
Total disbursements			26,858.80
Balance Nov. 30, 1914			142.44
Consisting of deposit, Wells Fargo Nevada National Bank			142.44

CONDITIONS IN AND AROUND THE SELBY SMELTER AND THE SELBY "SMOKE ZONE."

By A. E. Wells.

INTRODUCTION.

A large proportion of the ores containing lead and copper together with the precious metals, gold and silver, treated at the various reduction plants of this country also contain more or less sulphur. This sulphur is usually present as sulphide of iron, lead, copper, or zinc. In the treatment of those ores most of this sulphur is oxidized to sulphur dioxide or to sulphur trioxide and as such is eliminated from the smelters through the waste gases. The sulphur dioxide is discharged into the air as a gas. The trioxide unites with the moisture present in the smelter emanations or in the outside air and forms fine particles or mist of sulphuric acid.

In the treatment of these ores in the various types of furnaces there are formed two other products, which, if not recovered, are discharged into the atmosphere as smoke. These two products are flue dust and fume. Flue dust consists of the fine particles of the furnace charge that have been driven off or drawn off mechanically by the gas currents. Fume consists of metals or metallic compounds that have been volatilized at the high temperatures of the furnaces, condensed at lower temperatures, and carried by the furnace gases into the flues. Sulphur trioxide and elemental sulphur, driven off from the furnaces and condensed, are also classed as fume.

The possibility of smelter emanations contaminating the atmosphere of areas contiguous to smelters to such an extent as to constitute a nuisance to people or a cause for damage to vegetable or animal life is dependent upon a number of conditions. Few of these conditions are the same in the case of different smelters, and it is not possible to enumerate the determining factors in an order of relative importance applicable in all cases.

In general, the rate and concentration at which these emanations are discharged from a smelter is the chief factor which determines whether their concentration in the atmosphere is sufficient to cause trouble. However, there are other factors of such great influence that, with the same quantity of gases, dust, and fume, very acute

and deleterious results may be produced under some conditions while other conditions may allow such rapid diffusion and dispersion of the smoke that no "smoke troubles" will result.

In this report on the conditions in and around the Selby smelter and the so-called Selby "smoke zone" the principal factors in regard to the emanations from the smelter will be discussed as follows:

1. Nature and quantity of dust, fume, and noxious gases discharged from the smelter.
2. Relative geographical positions of the smelter and the "smoke zone."
3. Topography of the smoke zone and the surrounding country.
4. General wind conditions.

NATURE AND QUANTITY OF DUST, FUME, AND NOXIOUS GASES DISCHARGED FROM THE SMELTER.

The Selby smelter is essentially a lead smelter. Its function is the reduction, recovery, and refinement of lead from a variety of ores and mill products received from various points in the Western States. As most of these ores contain gold and silver, these precious metals also are recovered and refined. Besides refining the gold and silver recovered from the ores and concentrates the plant receives from outside sources a considerable amount of impure bullion and high-grade gold and silver concentrates. Several of the ores received at the plant contain small amounts of copper. This copper is made into the commercial copper sulphate "bluestone." The products of the smelter are refined gold, refined silver, lead bars, white lead lead shot, and bluestone.

CLASSIFICATION OF MATERIAL TREATED.

The ores received for treatment may be classed under four heads

1. Direct smelting ores:
   (*a*) Siliceous ores.
   (*b*) Oxidized lead ores.
2. California iron sulphide ores:
   (*a*) Raw sulphide ores.
   (*b*) Preroasted ores.
3. High-grade gold and silver concentrates and lead-bearing iron sulphide ores.
4. Products from lead concentrators:
   (*a*) Concentrates.
   (*b*) Middlings.
   (*c*) Slimes.

The ores of the first class contain very little sulphur and for the most part are treated directly in the blast furnaces.

The California sulphurets (2, *a*) contain about 40 per cent sulphur. Prior to 1913 there was received at the smelter a considerable tonnage of these raw sulphides. At the present time these raw sulphides are first roasted at an acid plant of the General Chemical Co., where about 95 per cent of the sulphur is eliminated from the ore and made into sulphuric acid. The roasted product (2, *b*) contains about 2 to 2.5 per cent sulphur when received at the Selby smelter.

The third class consists of a variety of mill concentrates containing gold and silver from Nevada and California. In this class are also included the sulphide ores that carry considerable lead. Ores of this class are not desired in the manufacture of sulphuric acid because of their relatively low sulphur content (between 10 and 30 per cent) and the possibility of high metal losses resulting from their treatment in the acid plant.

The fourth class comprises all the concentrated lead products received at the smelter. These are chiefly from the Coeur d'Alene district, Idaho, and include all the valuable mill products, concentrates, middlings, and slimes. They furnish the bulk of the lead supply to the plant.

METALLURGICAL FURNACES OPERATED AT THE SELBY SMELTER AND THEIR GASEOUS AND SOLID PRODUCTS.

The metallurgical furnaces operated at the Selby smelter may be classified as follows:

1. Roasting department:
   - Dwight & Lloyd sintering machines.
   - Ropp straight-line roaster.
2. Smelting department:
   - Blast furnaces.
3. Lead refinery:
   - Softening furnaces.
   - Desilverizing kettles.
   - Refining furnaces.
   - Merchant kettles.
4. Gold and silver refinery:
   - Retorts and condensers.
   - Cupelling furnaces.
   - Parting kettles.
   - Melting furnaces.

ROASTING DEPARTMENT.

Before smelting the material classed under 2, 3, and 4—that is, the sulphides and concentrates—it is necessary to eliminate as much of the sulphur as possible. The elimination is effected by a roasting

process, in which the material in pulverulent form is heated in the presence of air to a temperature at which the sulphur will unite with the oxygen of the air to form sulphur dioxide. All of the sulphur dioxide, except a comparatively small portion which is further oxidized to sulphur trioxide, passes off from the charge as a gas.

For many years prior to 1912 most of the roasting at the Selby plant was carried on in Ropp straight-line furnaces. These roasters were built of brick, of the flat-hearth reverberatory type, and heated by oil fire. The charge was dropped in at one end of the furnace and slowly moved to the other by mechanically operated rabbles or plows. In moving the material through the furnace the rabbles turned it over frequently and effected the necessary exposure of the particles to the heated air passing through the furnace. This turning over by the rabbles produced a certain amount of flue dust, which was carried out of the furnace by the air and gas currents into the flue and stack. A considerable portion of the dust escaped into the atmosphere, the remainder settling in the flues. The temperature in the furnace was sufficiently high to cause oxidation and volatilization of some of the metals, especially lead and arsenic. These were carried out of the furnaces, condensation to fume taking place either before or after leaving the furnaces. Thus the Ropp roaster was a source of sulphur dioxide gas, sulphur trioxide fume, flue dust, and fumes of volatilized metallic compounds.

During the last three years the practice of roasting in the Ropp roasters has been gradually superseded by that of roasting on the Dwight & Lloyd sintering machines. There now remains only one Ropp roaster, and this is operated only for special purposes. Not only is the operation carried on at a lesser expense by use of the sintering machines, but the product from the roast is sintered, and therefore is in much better physical condition for the subsequent smelting operation.

DWIGHT & LLOYD SINTERING MACHINE.

The Dwight & Lloyd sintering machine (fig. 5) consists essentially of a train of cast-iron or cast-steel pallets in the form of an endless conveyor, moved by suitable gears and sprocket wheels. Each pallet is 42 inches wide by 24 inches long and 10 inches deep. The bottom of each pallet consists of perforated or slotted grates. Beneath the horizontal portion of this endless pallet conveyor are two sheet-iron "wind boxes," which are connected by suitable sheet-iron pipes to a Sirocco vacuum fan. The sides of the wind boxes are bolted at the tops to iron castings which form the bearing surfaces for the pallets as they pass over them, thus making an air-tight joint. The pallets are each provided with four wheels, which engage on tracks for the travel of the pallets on the under side of the endless circuit.

The ore or charge is fed, in an even layer, onto the pallets just as they come to a horizontal position. As they are pushed forward to a point above the first wind box, the ore is subjected to an oil flame under a heated muffle, and the sulphur of the charge on its top surface is ignited. The combustion is maintained by the air drawn down through the charge and through the perforations in the grates into the wind boxes, by the down draft created by the fan. The roasting proceeds downward until it meets the grates. During the roast the material on the pallets has become agglomerated or sintered. The sintered product is discharged at the end of the horizontal line of pallets by the tipping and dropping of the pallets as they are pushed forward by those behind.

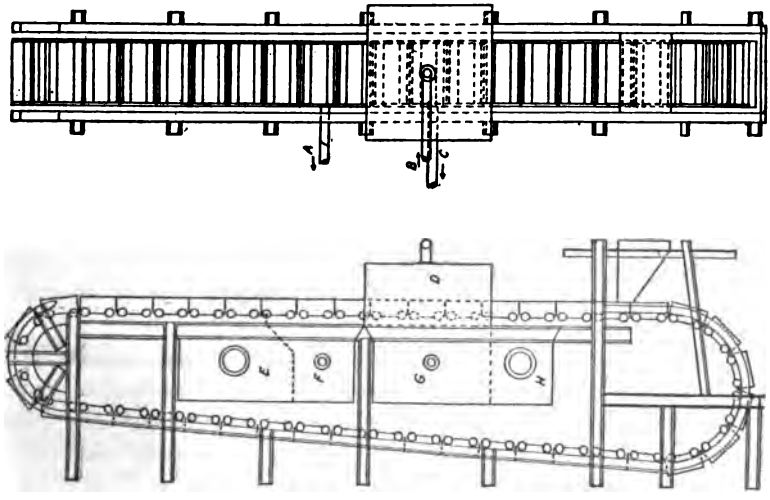

FIGURE 5.—Dwight & Lloyd sintering machine.

The percentage of sulphur eliminated from the charge varies greatly (between 50 and 75 per cent) according to the nature of the charge, the mixture, the ignition, and the speed of travel of the machine. During the year 1913, the average sulphur content of the charge was 13 per cent, and of the sintered product 4.2 per cent; thus the average sulphur elimination was 70 per cent.

At the present time the practice at the Selby smelter is to roast and sinter on the Dwight & Lloyd sintering machines practically all the material classified under 2, 3, and 4 in combination with some fine or crushed siliceous ores, added to give the charge such composition as will produce a good sinter. The preroasted California sulphides (2, *b*) are very fine and are not suited for direct smelting. They therefore form a portion of the charge to the sintering machines. To this mixture are added also certain smelter by-products, such as flue dust and crushed matte.

Not only are the sintering machines a source of sulphur dioxide gas, but a small amount of the fine ore is drawn through the grates by the force of the air currents and carried into the flues as "flue dust." Also the heat of combustion causes the oxidation and volatilization of some of the metals, as lead and arsenic. These are drawn off from the charge as vapor, condensed at lower temperatures, and are present in the flues as "fume."

SMELTING DEPARTMENT.

BLAST FURNACES.

The sintered product from the Dwight & Lloyd machines, or the product from the Ropp roasters, is mixed with the siliceous ores and oxidized lead ores (class 1), with the necessary lime rock for fluxing, and, with coke for fuel, charged into the blast furnaces, and smelted.

The blast furnaces at the Selby smelter are rectangular shaft furnaces 36 inches wide and 144 inches long in cross section at the tuyère line, and about 14 feet high. The lower part of the shaft consists of sheet-iron jackets, above which the shaft is constructed with brick. Air is blown in continuously through circular openings, "tuyères," in the water jackets. The ore, flux, and fuel mixture is fed in at the top of the furnace by hand labor at intervals in order to keep the shaft full to the right height while the charge is smelted and removed at the bottom.

The air blown into the furnace is insufficient to oxidize all the carbon of the coke to carbon dioxide, and considerable carbon monoxide is formed. This reducing gas, rising through the charge in the furnace, reduces some of the lead and the precious metals to the metallic state, the lead collecting the gold and silver as it drips down through the mass. At the point where the coke is incandescent and where the combustion is the most rapid the rest of the lead and precious metals are reduced. At this point the temperature is sufficiently high to cause the formation of a "slag" from the waste portions of the charge. Owing to the reducing atmosphere in the lead blast furnace, very little, if any, of the sulphur present is oxidized to sulphur dioxide. Most of it combines with the copper present in the charge, and with some of the iron and lead to form "matte," which flows out from the furnace with the "slag."

The lead which contains most of the gold and silver, being heavier than either the matte or the slag, settles into the crucible of the furnace, below the point where the slag and matte are tapped out. This lead bullion is removed from the furnace through a separate siphon tap.

The slag and matte are tapped into a settler, where the matte, being heavier than the slag, settles to the bottom and the slag over-

flows into slag pots set on trucks. The waste slag is then tapped out from the slag pots onto the dump. At intervals the matte is tapped out into special cast-iron pans and cooled. The cooled matte is then crushed and roasted. At the present time the greater part of the matte is roasted over the sintering machines, and such will undoubtedly be the practice in the future. Several times during the year it is the practice to accumulate the matte of highest copper content and roast this separately in the Ropp roaster. This matte is then smelted with siliceous ores and flux in a special smelting operation and the grade of the matte raised to about 40 or 45 per cent copper. This high-grade matte is then given a "sulphatizing roast" to convert the sulphur into sulphate for the purpose of leaching and the production of "bluestone."

The lead bullion from the blast furnace is cast into bars and taken to the lead refinery.

As very little of the sulphur charged into the blast furnaces is oxidized in the furnace, the blast-furnace gases are therefore practically free from sulphur dioxide. As a source of sulphur dioxide contamination to the atmosphere the blast-furnace gases are negligible.

However, the blast furnaces do produce a considerable amount of flue dust and fume, which are carried into the flues by the gas currents, and which, if not recovered, are carried out into the atmosphere.

LEAD REFINERY.

SOFTENING FURNACE.

The lead bullion from the blast furnace is melted down slowly in a softening furnace. This furnace is of the reverberatory type, and is heated with oil. In the softening furnace some of the impurities in the lead are removed by oxidation and liquation. The principal impurities are copper, arsenic, and antimony, which on being oxidized in the furnace form a scum or dross on the surface of the melted lead. These are removed by skimming. A very small amount of these impurities may be volatilized to form fume.

DESILVERIZING KETTLE.

From the softening furnace the lead is run into the desilverizing kettle. In this kettle zinc shavings or dust are stirred into the lead while it is kept at the proper temperature by an oil fire. An alloy of zinc, lead, gold, and silver is formed, which appears as a dross. This dross is skimmed off into a Howard press, which serves to eliminate the greater portion of the lead carried mechanically by the dross and to retain the "dry" lead-zinc crust containing the gold and the silver.

REFINING FURNACE.

The desilverized lead is tapped or siphoned from the kettle into a refining furnace, where the zinc that is still in solution is oxidized and removed. The refined lead is then tapped into the "merchant kettle," from which it is cast into the commercial bars.

With the exception of the small amount of arsenic, antimony, or zinc fume that may be evolved from the softening and refining furnaces, there are no emanations from the lead refinery to contaminate the atmosphere. The only gases present are those from the combustion of the oil required to heat the furnaces.

GOLD AND SILVER REFINERY.

RETORTS AND CONDENSERS.

The gold, silver, lead, and zinc alloy crusts from the desilverizing kettle are placed into retort furnaces, where the zinc is oxidized and volatilized. The zinc fumes are condensed as metallic zinc in suitable condensers. This zinc is used again in the desilverizing kettle.

CUPELLING FURNACE.

The residual lead, gold, and silver alloy from the retorts goes to a cupelling furnace. In this furnace the lead is oxidized and skimmed off as lead oxide (litharge). The gold and silver bullion left in the furnace is known as doré. This furnace is a source of lead fume.

PARTING KETTLES.

The gold and silver alloy from the cupelling furnace (doré bullion) is placed in cast-iron kettles and treated with sulphuric acid to dissolve the silver from the gold. In the boiling of this acid, to effect solution of the silver, there are evolved large amounts of sulphur trioxide vapors, which form fume. The fume—fine particles of sulphuric acid—is carried into the flue, and if not recovered passes out into the air. The silver in solution is precipitated in tanks by copper.

MELTING FURNACES.

The gold residue from the parting kettle and the silver precipitates from the tanks are melted down in separate melting furnaces and cast into bars.

Melting furnaces are also used for the melting down of certain high-grade materials received at the plant to remove some of the impurities and to prepare the metals for cupellation or parting.

From the above very brief outline of the work performed in the gold and silver refinery it is evident that there are two fume products that might be discharged into the atmosphere, namely, the lead fume from the cupelling furnaces and the acid fume from the parting kettles.

The preceding brief description of the furnaces and processes employed for the reduction and refining of the lead, silver, and gold from the materials received at the Selby smelter serves to make evident that the principal sources of sulphur dioxide gas, flue dust, and fume are: (1) The roasting furnaces; (2) the blast furnaces; (3) the parting kettles. The minor sources are: (4) Lead softening and refining furnaces; (5) cupelling furnaces.

ELIMINATION OF SULPHUR FROM THE SELBY SMELTER.

Practically all of the sulphur originally present in the ores and concentrates received at the smelter is eliminated in either the roasters or in the blast furnaces.

During the year 1913 the elimination of sulphur by these furnaces was approximately as shown below:

	Per cent.
(*a*) From roasters:	
Sintering machine gases	63
Ropp roaster gases—	
From ore	14
From matte	14
(*b*) From blast furnaces:	
In blast-furnace gases	3
In blast-furnace slag	6

Under the present method of operation, that is, without the use of the Ropp roaster, over 90 per cent of the total sulphur is being eliminated in the sintering-machine gases and 3 per cent in the blast-furnace gases.

During the years January 1, 1910, to May 15, 1914, the sulphur eliminated from the plant in the roaster gases was as shown in the following diagrams:

Figure 1 shows the average daily sulphur output for each month during the period January 1, 1910, to May 15, 1914.

Plate VIII shows the daily output between March 15, 1913, and May 15, 1914.

Table 1, below, gives the average daily output per year, with the maximum for 1910, 1911, 1912, 1913, and January 1 to May 15, 1914.

TABLE 1.—*Sulphur eliminated in roaster gases.*

Year.	Sulphur eliminated.	
	Average.	Maximum.
	Tons per day.	*Tons per day.*
1910	24.9	53.5
1911	25.5	42.9
1912	26.7	41.4
1913	24.4	42.8
1914	28.3	44.6

A small percentage of this sulphur may have been eliminated as elemental unoxidized sulphur, especially during the time that raw California sulphurets were being treated on the sintering machines. However, the average amount of sulphur so eliminated is so small that it may be disregarded in this discussion, and all of the sulphur considered to have been oxidized to dioxide or trioxide.

The relative amounts of sulphur dioxide or trioxide produced in the roasting furnaces are variable and depend largely upon the charge and the operating conditions.

In the Ropp roasters a considerable amount of sulphur trioxide is produced, especially when roasting matte. On the Dwight & Lloyd sintering machines, the conversion to sulphur trioxide is only slight. Under the charge and operating conditions existing during the investigations for the commission, the relative amounts of SO_2 and free SO_3 found in the gases from the furnaces were as follows:

TABLE 2.—*Relative quantities of sulphur dioxide and sulphur trioxide in roaster gases—Average data for October and November, 1913.*

Roaster.	Place of sampling.	Quantity of SO_2 per cubic meter at 0° C. and 760 mm.	Quantity of SO_3 per cubic meter at 0° C. and 760 mm.	Ratio of SO_2 to SO_3 by weight.
		Grams.	*Grams.*	
Single sintering machine	Stack	17.16	0–0.50	>35.0
Ropp roaster on ore	Flue	17.80	1.20	15.0
Ropp roaster on matte	Stack	1.14	.45	2.5

The following, Table 3, gives the percentage of sulphur dioxide present and the volume of the gases discharged from the roaster stack during the days on which tests were made in October and November, 1913:

TABLE 3.—*Roaster-stack data—Averages for October and November, 1913.*

Number of Dwight & Lloyd machines.	Number of Ropp roasters on matte.	Number of Ropp roasters on ore.	Temperature of gases.	Volume of gases at 0° and 760 mm.	Average proportion of SO_2, by volume.
			°C.	*Cubic feet per minute.*	*Per cent.*
1	0	0	55	24,000	0.60
1	1	0	120	32,000	.70
2	1	0	155	35,000	1.30
2	0	1	160	35,000	1.60
0	[a] 1	0	110	30,000	.10

[a] Sulphatizing roast, matte roasted for "bluestone."

In May, 1914, when the gases from the sintering machines were being filtered through the bag house the average stack data obtained were as given in Table 4.

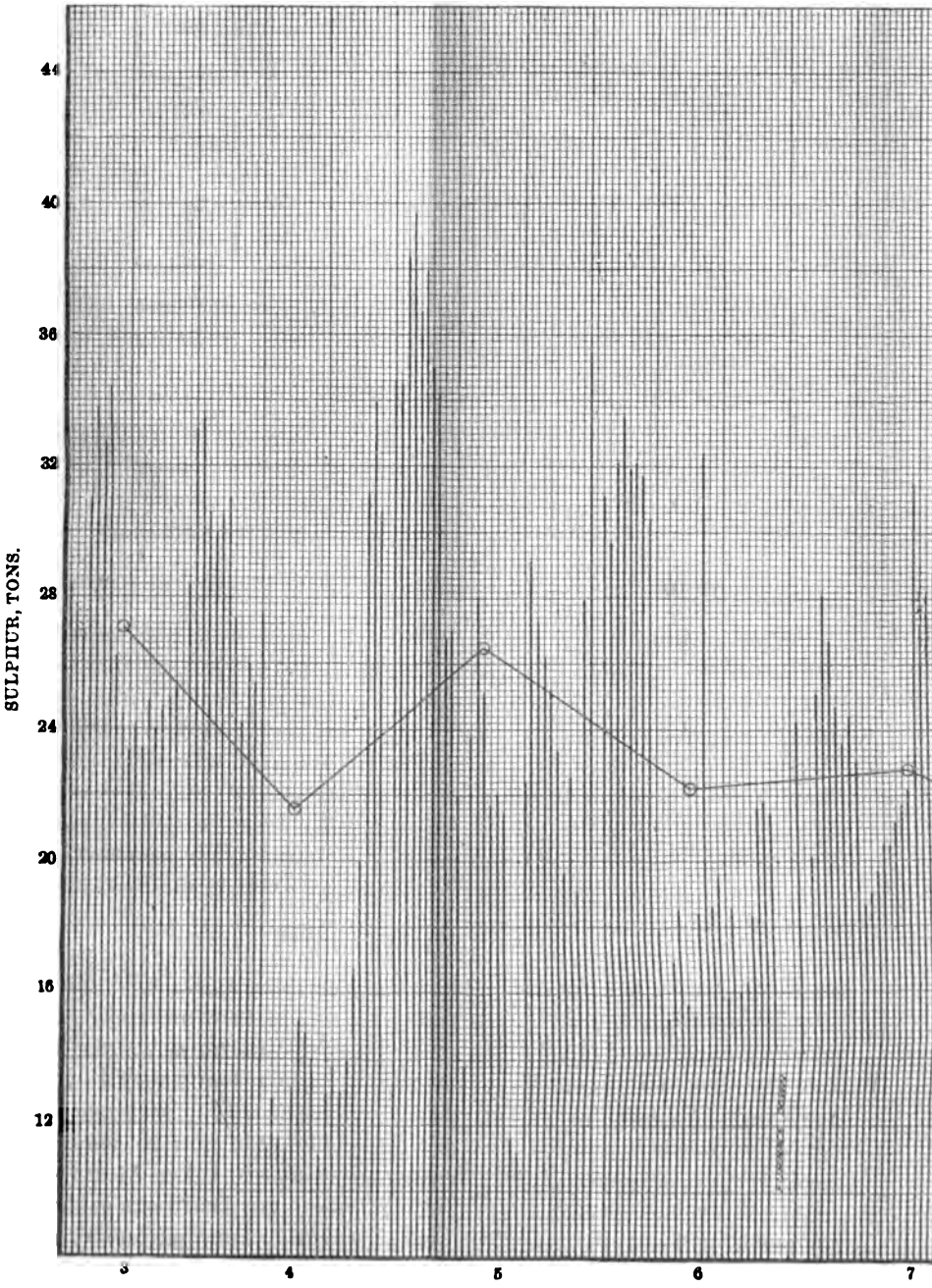
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TABLE 4.—*Roaster-stack data—Averages for May, 1914.*

Number of furnaces in operation.			Temperature of gases.	Volume of gases at 0° C. and 760 mm.	Average proportion of SO_2 by volume.
Dwight & Lloyd machines.	Ropp roasters on matte.	Ropp roasters on ore.			
			°C.	*Cubic feet. per minute.*	*Per cent.*
3	0	1	130	40,000	1.50
3	0	0	105	24,000	1.70
2	0	0	90	20,000	1.40
1	0	0	70	18,000	.75

These measurements were made at a point about 60 feet above the base of the stack. The sampling platform is shown in Plate V, *B*.

SULPHUR DIOXIDE IN BLAST-FURNACE GASES.

Samples were taken of the blast-furnace gases as they passed into the bag house. These samples averaged 0.04 per cent SO_2 or 400 parts SO_2 per million by volume. No measurements of the volume of the blast-furnace gases were made.

RECOVERY OF FLUE DUST AND FUME FROM THE BLAST-FURNACE GASES.

During the whole operating period of the plant prior to 1908 the fume and a considerable portion of the flue dust produced by the blast furnaces were allowed to escape into the atmosphere. It is true that these products were conducted through some length of flue system. By this practice only the coarser particles of dust were settled out. As the lead-flume and flue-dust losses from the furnaces during those years were high, it is safe to assume that a comparatively large tonnage of this fume and dust was discharged into the air before the installation of the bag house in March, 1908.

CONSTRUCTION OF BAG HOUSE.

Plate V, *C*, shows the outside view of the blast-furnace bag house taken from the west side. This bag house is built of reinforced concrete and is approximately 125 feet long, 90 feet wide, and 68 feet high. Fifteen feet above the ground is a sheet-iron floor covered with concrete. This floor divides the bag house into two chambers, an upper or bag chamber, and a lower or dust chamber. In the floor are 18-inch holes provided with clay-tiling thimbles. Over these thimbles are fitted the lower ends of bags, which are suspended from rods extending across the top of the chamber. In the bag house are 1,920 woolen bags 18 inches in diameter, 30 feet long, with an effective length of about 28½ feet. The bag house is divided into eight compartments by seven partition walls.

OPERATION OF BAG HOUSE.

The gases and fumes driven off from the blast furnaces are drawn through flues by a 12-foot fan, and driven into the bag house below the thimble floor. They are then forced up through the bags. At the temperature of the bag house, less than 230° F., all the metallic fumes are in the solid state. In passing through the bags all of the solids as dust and fume are filtered out; only the gases pass through. These filtered gases are conducted to the 180-foot steel stack (Pl. IV, *A*), from which they are discharged into the atmosphere. Thus the gases passing out of the stack are oxygen, nitrogen, carbon dioxide, and a small percentage of sulphide dioxide and carbon monoxide. As stated above, the sulphur dioxide content of these gases is about 0.04 per cent.

The bags are shaken at intervals by mechanical shakers and the dust adhering to them drops into the dust chamber below. The dust and fume collected contains about 50 per cent lead and 20 per cent arsenic. Analyses of dust samples taken in the months of April to July, 1914, were made by Mr. J. R. Marston, with results as follows:

Analyses of fume and dust from blast-furnace bag house.

Month.	Silica.	Iron.	Sulphur.	Arsenic.	Lead.	Cadmium.	Antimony.
1914.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
April	0.5	0.6	4.5	19.9	49.0	4.0	0.4
May	.5	.2	3.5	19.6	49.0	3.7	.4
June	.4	.5	6.6	11.5	58.2	3.5	.4
July	.6	.7	7.8	4.6	70.8	2.0	.4

Whenever there is an accumulation of this dust in a compartment the material is burned "in situ" by igniting it with oil-saturated waste. In the combustion of this fume there is generated sufficient heat to volatilize some of the compounds, especially the arsenical ones. These are drawn off by a special fan and refiltered in a special compartment of the house. The product of this combustion of the fume is a loosely sintered mass which is resmelted.

Since the installation of the bag house in March, 1908, the solid particles and fume from the blast furnaces have been discharged into the air only at rare intervals and then for brief periods. For a short period each day, about 10 minutes, when the bags are being cleaned, the dust and fume are discharged into the air. Occasionally a bag will tear out or drop from its wire, in which case a small amount of dust and fume will escape until the bag can be replaced.

RECOVERY OF FUMES FROM THE REFINERY.

In the discussion of the emanations from the lead softening and refining furnace and the cupelling furnace, it was pointed out that from each a small amount of fume was produced. As these fumes are now filtered through the blast-furnace bag house, they do not now constitute a source of atmospheric contamination. At the present time it is the practice to put all the gases from the oil fires used to heat these furnaces and the melting furnaces through this bag house. Thus all the emanations from the refining furnaces, except from the parting kettles, are handled in the blast-furnace bag house.

Prior to 1909 the dense white fumes of sulphur trioxide, or the sulphuric acid mist, from the parting kettles were allowed to escape directly into the air. They could not be filtered through bags because of the corrosive action of the acid on the bags. In 1909 the Cottrell electrical precipitation process was installed for the recovery of these fumes. The fumes from the parting kettles are now conducted into a lead-lined flue 4 by 4 feet, in which are placed vertical lead plates 4 inches wide and 4 feet long, alternating with suspended lead-covered iron rods provided with mica points. A difference of electrical potential of 17,000 volts is maintained between the electrodes. As the fumes pass through this electrical field they are electrified and drawn to the plate electrode where they are precipitated. The potential is obtained by transforming an alternating 460-volt, 60-cycle current to 17,000 volts, passing the current through a rectifier, which gives at the electrodes an intermittent direct current of about the same voltage. This apparatus has been highly efficient in removing the fumes evolved from the parting kettles, and they do not now furnish a source of contamination to the atmosphere.

RECOVERY OF FLUE DUST AND FUMES FROM THE ROASTER AND THE SINTERING MACHINES.

When the roasting operations of the plant were carried out in the Ropp roasters, there was no possibility of filtering the gases through bags without the employment of a large amount of a neutralizing agent for the neutralization of the sulphur trioxide or the acid present. Instead of working along these lines, the Selby management, in 1909 and 1910, tried to effect a precipitation of this dust and fume by the application of the Cottrell process.

An experimental flue, 6 feet 6 inches by 30 feet long, was equipped to handle about 50,000 cubic feet of gas per minute. The flue contained 38 rows of 16 plates, each 6 feet long and 4 inches wide. These plates were alternated with the several types of discharge electrodes used. Considerable difficulty was experienced in carrying on a continuous operation of the process, due to the muddy character of the

material collected. The installation of an operating unit was never carried out. Thus until April of this year the fume and dust from the roasters were discharged into the atmosphere (see Pl. IV *B*), the only recovery made being what was obtained by settling in the flue system.

With the substitution of the sintering machines for the Ropp roasters, the possibility of filtering the roaster gases through bags became greater. During 1913 several investigations were made by the company to determine the acid content of the gases from the sintering machines. It was found that the conditions were favorable for the operation of a bag house. There was present very little elemental sulphur, which had been the cause of trouble at other plants where attempts had been made to filter sintering-machine gases. Furthermore, owing to the presence of considerable zinc and lead on the charge, the sulphur trioxide formed in the roast was to a great extent neutralized by fumes of those metals.

When requested by the Selby Smelter Commission to remove the fume and dust from the roaster gases, the Selby management constructed a bag house instead of installing the Cottrell process for this purpose. It was recognized that, if in the future it was necessary to operate the Ropp roaster during the "closed season," it would be necessary to neutralize the gases from that furnace to permit of their being filtered or treat them by the Cottrell process.

The bag house for the roaster gases (Pl. IX, *A*) is 45 feet long, 30 feet wide, and 50 feet high. It is built of reinforced concrete and is divided into four sections by partition walls. Each section contains 75 bags, 30 feet long and 18 inches in diameter. Beneath the thimble floor are constructed sheet-iron hoppers into which the collected dust is dropped when the bags are shaken. The bottoms of these hoppers are V shaped, and are provided with gates for the removal of the dust into cars which can be pushed in on tracks below.

The gases and fume drawn off from the sintering machines by the Sirocco fans are discharged into a brick flue. From this brick flue they are drawn by a 5-foot Sirocco-type fan, capacity of about 30,000 cubic feet per minute, around a system of steel balloon flues, in which some of the coarse dust particles are settled by gravity, and the gases are cooled. The gases are then forced through the bags. After passing through the bags, the filtered gases from the top of the bag house are conducted by a steel flue to the brick stack (Pl. IV, *C*), from the top of which, 160 feet above the ground, they are discharged into the air.

The temperature of the bag house is about 200° F., at which temperature all of the volatilized lead, arsenic, and other metallic compounds are in the fume state and are effectively removed.

A. BAG HOUSE FOR ROASTER GASES.

B. GENERAL VIEW OF SMELTER STACKS, SEPTEMBER, 1914.

C. VIEW TOWARD WEST ALONG THE STRAITS FROM STATION 2.

Due to a rather inefficient shaking device used for cleaning the bags, some little trouble was experienced at first in maintaining a continuous operation of this bag house. Being improperly cleaned the bags offered such a resistance to the passage of the gases that the bag-house fan could not drive through them the gases coming from the individual fans of the sintering machines. However, this difficulty has been successfully overcome by a more efficient shaking device and by more frequent shakings. Since the first of May, 1914, this bag house has been operating very satisfactorily.

A good record of the dust and fume that was discharged from the Selby roaster stack during the years that the plant has been in operation is not to be had. The amount discharged per day was undoubtedly very variable, depending upon charge and operating conditions

Analyses made by Mr. Marston of the monthly samples taken from the bag-house dust are given below.

Results of analyses of dust from sintering-machine bag house.

Month.	Silica.	Iron.	Sulphur.	Arsenic.	Lead.	Zinc.	Antimony.
1914.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
April	0.5	0.5	7.4	2.3	70.4	0.2	0.3
May	.4	.6	5.8	9.7	64.4	.3	.2
June	.9	2.1	7.2	4.8	66.6	1.4	.2
July	.5	1.1	7.0	4.9	67.3	1.2	.1

During May and June the amount of dust recovered in the bag house varied from 3,000 pounds to 5,000 pounds, averaging about 4,000 pounds. At times there was a very small amount of visible smoke, showing that some fume was escaping.

On May 5 and 6, and again on the 16th, tests were made by chemists of the commission to determine the amount of lead and arsenic that was still being discharged from the roaster stack. On May 5 and 6 there was a slight amount of visible smoke escaping from the stack. Due to a mistake in placing a damper in the flue, some of the unfiltered gases were allowed to pass directly into the stack during the time that about 7 per cent of the total sample was taken on May 16.

Measured volumes of the gas were drawn out from several points in the cross section of the stack at a point about 60 feet above the ground. These volumes were filtered through a Brady filter and the solid material collected in the filter analyzed for lead and arsenic. On each of these days there were three sintering machines in operation. The results, given below, show that even with a slight visible smoke from the bag house, the efficiency of the bags is about 96 per cent. With the better results obtained since the improvement in the shaking device, the efficiency has been greater.

TABLE 5.—*Results of tests to determine quantity of lead and arsenic being discharged from the roaster stack after the installation of the sintering-machine bag house.*

Item.	May 5-6.	May 16.
Data regarding gases in stack:		
Temperature, °C	95	80
Velocity, feet per minute	520	525
Volume, cubic feet per minute at flue temperature	32,800	33,000
Volume, cubic feet per minute at 0° C. and 760 mm	24,500	25,500
Volume sample, cubic feet at 0° C. and 760 mm	19.52	10.75
Lead present—		
In sample, grams	0.024	0.015
Per cubic foot, grams	0.00123	0.0014
Arsenic present—		
In sample, grams	0.0020	0.0015
Per cubic foot, grams	0.00010	0.00014
Rate of discharge of fume:		
Lead per minute, pounds	0.067	0.078
Lead per 24 hours, pounds	96	113
Arsenic per minute, pounds	0.0054	0.0079
Arsenic per 24 hours, pounds	8	11

From the foregoing discussion it is evident that the only smelter emanations that have been contaminating the atmosphere in the vicinity of the Selby plant during the investigation of the Selby Smelter Commission have been the dust and fumes from the roasters during part of the period and the sulphur dioxide from the roasters during the whole period.

RELATIVE GEOGRAPHICAL POSITIONS OF THE SMELTER AND THE "SMOKE ZONE."

The Selby smelter is situated near Vallejo Junction in Contra Costa County, at the western end and on the south shore of the Carquinez Straits, where the straits open out into San Pablo Bay.

The city of Benicia is situated in Solano County, at the other end of the straits, in a line almost due east, and about 4½ miles from the smelter. The general direction of the straits is east and west.

As indicated on Plates VI, VII, and XXXVIII, the territory included in the "smoke zone" of the Selby smelter lies north of the straits and south of the highway between the cities of Benicia and Vallejo, east from Vallejo to near the turn of the road at B, at the Midway House. East of this point, the extreme northern line is rather indefinite but may be taken as following a northeasterly line from B to the Sulphur Springs Valley Creek, and following the creek down to Suisun Bay.

The nearest point of this district to the smelter is a point of land known locally as "Dead Man's Point," this point being 1 mile distant from Selby. The most remote point where smoke damage or nuisance was claimed was about 6 miles distant from the smelter.

TOPOGRAPHY OF THE SMOKE ZONE AND THE SURROUNDING COUNTRY.

Rising abruptly from the water on both sides of the straits are fairly high hills or bluffs, which form a natural air channel or chute between the Selby smelter and Benicia.

Except for a single canyon south from Crockett, 1 mile east of the smelter, the bluffs on the south side are practically continuous and average between 200 and 400 feet in height above the straits.

On the north side of the straits the line of bluffs nearest the water is not so high, and has receded for short distances at Dos Reis Cove, at Elliot Cove, at Glen Cove, and for a considerable distance at Southampton Bay. In the recession at Southampton Bay is a considerable area of marsh land. Between Glen Cove and Southampton Bay is a high promontory known as Dillon Point, at the top of which is located the North Tower of the Pacific Gas & Electric Co.'s power line.

East of Southampton Bay the hills continue, their crests running in a general southeast or easterly direction. Between these hills and the straits, occupying a strip of land about 3 miles in length, and varying between 100 yards and 1 mile in width, are situated the residential and business portions of the city of Benicia.

Except for the narrow strip included in the Benicia city limits, the country is very hilly and is devoted to agriculture and stock raising.

With such topography it is evident that when the wind is from the west the smoke from the Selby smelter is blown along the straits past Dillon Point directly toward and over Benicia. Under a wind slightly south of west, the smoke is blown across the straits toward Elliot and Glen Cove and over the agricultural district. When there is only a slight drift of air from these directions the smoke tends to drift along the straits and settle back up into the coves and depressions in the bluffs on the north.

Between the promontory at Dillon Point where the north tower is located and the hill directly north is a slight depression which serves as a sort of channel for the air currents that swing in close to the north shore of the straits.

GENERAL WIND CONDITIONS IN THE SELBY SMOKE ZONE FOR A PERIOD OF YEARS.

During the last few years a very complete record of the direction and velocity of the wind has been kept at the Selby smelter. The observations were made six times every 24 hours, at 3 a. m., 7 a. m., 11 a. m., 3 p. m., 7 p. m., and 11 p. m., by certain men who were on duty at those hours. Believing that those wind records are suffi-

ciently accurate, and as they were found to check fairly well with the observations of the field men of the commission during the time the field work was going on, the data from these records have been used in the discussion of the general wind conditions of the "smoke zone."

The data of 1911, 1912, and 1913 are tabulated in the following table, showing the percentage of the total number of observations each month, made when the wind was in each of the several directions indicated. These data are represented graphically in figures 2, 3, and 4.

TABLE 6.—*Directions of wind—Percentages of total records by months.*

Month.	North.	North-east.	East.	South-east.	South.	South-west.[a]	West.	North-west.	Calm.
1911.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*
January	.....	1.1	32.3	1.1	7.5	26.3	4.3	.....	27.4
February	1.2	2.4	22.0	1.2	8.3	20.2	12.5	5.4	26.8
March	.....	1.0	19.9	.....	6.5	39.8	16.7	1.6	14.5
April	2.2	1.1	.5	.....	3.3	56.8	26.2	.5	9.4
May	1.7	.....	1.1	.....	.6	65.1	24.2	2.8	4.5
June	.....	.....	.....	.....	1.1	93.2	4.0	.....	1.7
July	1.1	.....	.....	.....	.5	89.8	7.5	.....	1.1
August	.....	.....	.....	.....	1.1	92.5	4.8	.....	1.6
September	.....	.....	.....	.....	.....	77.8	12.2	.....	10.0
October	1.1	.5	11.3	1.1	1.1	42.5	17.2	.5	24.7
November	.6	.6	27.8	1.6	.5	27.8	6.7	3.9	30.5
December	3.2	5.9	30.2	.5	2.1	15.1	7.0	5.4	30.6
1912.									
January	.....	2.7	41.9	1.6	5.8	16.1	2.2	.....	29.7
February	7.5	1.1	10.3	.....	.5	35.7	12.1	9.2	23.6
March	2.7	2.2	11.5	2.2	3.3	49.7	13.1	1.6	13.7
April	.....	.....	1.1	.5	2.9	58.1	25.9	6.3	5.2
May	.....	.....	.5	.....	2.7	78.8	8.2	.5	9.3
June	1.2	.....	3.8	.6	2.5	72.2	10.2	.6	8.9
July	.....	.....	.....	.....	.....	86.6	11.8	.....	1.6
August	1.1	.....	.....	.....	.....	83.9	11.8	.5	2.7
September	.....	.5	.5	.....	3.9	66.7	17.2	.5	10.7
October	1.6	6.5	1.6	1.6	1.1	42.4	12.4	1.6	31.2
November	.....	5.5	23.4	5.0	5.5	22.9	9.4	1.1	27.2
December	3.7	6.5	23.7	1.6	2.1	26.4	5.4	1.6	29.0
1913.									
January	4.5	3.9	22.9	6.7	7.3	29.1	3.3	.....	22.3
February	5.3	4.2	14.9	3.6	2.4	28.6	17.8	2.4	20.8
March	1.6	1.1	7.0	1.1	5.4	38.7	30.1	3.2	11.8
April	.5	1.6	2.2	.5	3.3	42.3	26.7	11.2	11.7
May	.5	.....	.5	.....	1.1	59.1	34.4	2.2	2.2
June	.....	.....	.....	.....	.....	67.9	30.5	1.1	.5
July	.....	.....	.5	.....	.....	76.9	17.2	1.6	3.8
August	.....	.5	.5	1.1	.....	60.8	28.5	.5	8.1
September	1.1	1.6	.....	.5	.....	57.6	17.9	.5	20.8
October	1.6	2.7	2.7	.....	1.6	44.2	6.8	3.2	37.2
November	1.1	3.3	14.4	3.3	7.8	31.7	12.8	3.9	21.7
December	.....	11.3	37.6	4.3	7.5	18.3	.5	1.1	19.4

[a] A southwest wind at the smelter usually means a wind almost west or only slightly south of west along the straits.

From these figures it is evident that during the months April to November the wind is from the west or southwest about 85 per cent of the time, and during several months of that period may be from that general direction 98 per cent of the time. During the other months of the year the wind is more variable and often calm. Even during the winter months the wind does blow from the west part of the time.

Thus during the months April to November, the smoke generally is blown or drifted toward Benicia or the agricultural district west or northwest of the city.

A study of the velocity records shows that during the April-November period (the period of the "trade winds") the general condition is a calm or very slight west wind during the early morning hours. During the morning the wind freshens and by noon it has attained a velocity of about 12 miles per hour. In the late evening the breeze gradually dies down.

SUMMARY.

On account of the geographical position of the Selby smelter and the "smoke zone," the topography of the surrounding and intervening country, and the general wind conditions existing during the greater part of the year, the Selby smelter is situated very unfortunately in so far as "smoke troubles" are concerned. To a degree not usual around most smelters, all of the natural conditions tend to retard the dispersion and diffusion of the dust, fume, and gases that might emanate from the smelter, and make them more concentrated over the "smoke zone" than would be expected. We must expect, therefore, that the elimination of a comparatively small amount of sulphur dioxide gas, dust, and fume from the Selby smelter would be more serious during eight months of the year than a larger amount emanating from smelters situated in more favorable locations.

INVESTIGATIONS TO DETERMINE THE EXTENT OF THE CONTAMINATION OF THE ATMOSPHERE IN THE SELBY "SMOKE ZONE" BY THE SMELTER EMANATIONS.

By A. E. Wells.

INVESTIGATION OF THE SULPHUR DIOXIDE CONTENT OF THE ATMOSPHERE IN THE SELBY "SMOKE ZONE."

A preliminary review of the conditions in the "smoke zone" of the Selby smelter indicated that here, as in practically all "smoke zones," it would be necessary to make an extended and detailed study of the sulphur dioxide content and other elements of the atmosphere before any conclusions could be reached concerning the extent of contamination caused by the smoke from the Selby smelter. Such a detailed study required the determination of the sulphur dioxide content at many points under all possible atmospheric and wind conditions. This study further necessitated a determination of the amount of contamination when the wind was blowing the smoke directly from the smelter over the "smoke zone" during periods of maximum and minimum discharge of sulphur dioxide. In order to determine the variation in the sulphur dioxide content, as well as the maximum contamination under the several conditions where slight variations produce great changes in the gas concentration, it was found necessary to take a great number of "instantaneous" samples. For the purpose of checking these "instantaneous" samples "continuous" samples were taken. The methods used for the "instantaneous" sampling, "continuous" sampling, and the methods of analysis of these samples are described in another section of this report.

As an aid in collecting the desired data from all parts of the "smoke zone" it was decided to equip a portable laboratory which could be moved from point to point and so stay in the smoke stream. For this purpose an automobile was equipped with the necessary analytical apparatus, cabinets, etc., as described on pp. 210–212. This automobile laboratory was equipped in San Francisco during August, 1913, and was used during the early part of September to make tests in and around San Francisco. The automobile laboratory arrived in Benicia on September 17, and until October 8 was the only apparatus used for making sulphur dioxide determinations in that district. Guided by the results obtained during that time, by personal observation;

concerning the general direction of the smoke stream, and by the statements made by many of the people in the district concerning the places where the smoke was most often observed, it was decided to establish and equip two fixed stations for analytical work to supplement the data obtained with the portable laboratory.

One of the stations was established at the point *1*, Plate VI, near the old mill by J. G. Fisher's house, on a low promontory in the western part of the city of Benicia. This point was in a line directly east of the smelter and 4 miles distant. A vacant house, situated about 200 feet back from and 30 feet above the water's edge, was used as a laboratory. All apparatus for the "instantaneous" samples and their analyses and for taking "continuous" samples was set up in the southwest room. From this station could be had an excellent view (Pl. X, *A*) of the straits in the direction of the smelter, which made general observations at this station of much value.

The Selby roaster stack itself could not be seen, but, previous to the installation of the bag house, the smoke from the stack could be seen very soon after it was discharged.

The "instantaneous" samples were taken either on the front porch or in the yard about 40 feet away from the house. The inlet tube to the absorption train for continuous samples extended through a window to the outside of the house. As the windows were kept open, there was a good circulation of air around the inlet, so that the air drawn in was a good sample.

The location of this station was such that the results obtained here represented the maximum contamination in the city of Benicia due to smoke coming from the west or from the Selby smelter. The greater portion of the residence section and the whole of the business section of Benicia are situated east or southeast of this station, and any smoke coming from the west, almost without exception, reaches this point first.

Because of its relative proximity to the smelter, the topography of the surrounding country, and the wind conditions existing during the period of the trade winds it was decided to locate a station at the point marked "station 2" (see Pl. VI) on the land leased by M. White, on Dillon Point near the North Tower of the Pacific Gas & Electric Co. Between the hill on which the tower is located and the hill directly north is a rather slight depression which serves as a natural funnel or draw, similar, though to a less degree, to that produced by the bluffs on the two sides of the straits. Thus, when the wind is very light and from the west or slightly south of west the smoke of the smelter drifts toward this point and tends to settle in this depression. During the time between September 18 and October 8 the smoke was found to be present at this place more often

and in greater strength than at any other point in the "smoke zone." Thus this point was selected as being the one where the maximum contamination of the atmosphere in the "smoke zone" of the Selby smelter would be found. This station was about 2½ miles from the smelter, in a direction about 8° north of east. From this station an excellent view of the straits west of Dillon Point and the top of the smelter roaster stack could be had. (See Pl. IX, *C*.)

During the time the smoke was visible—that is, before the installation of the roaster bag house—the smoke could be seen issuing from this stack. When the wind was from the south, southwest, west, or northwest it could be followed by the eye for a considerable distance.

GENERAL SUMMARY REGARDING ALL "INSTANTANEOUS" SAMPLES IN SELBY "SMOKE ZONE."

The total number of "instantaneous" samples taken in the Selby "smoke zone" was 4,862, of which 1,955, or 40.2 per cent, were taken at the Benicia station (station 1), 1,674, or 34.4 per cent, were taken at the station on White's ranch (station 2), and 1,233, or 25.4 per cent, were taken with the automobile equipment at a great many points. This sampling and the analyses extended through six months of active field work. Table 7 shows the distribution of these samples.

TABLE 7.—*Time of taking and number of "instantaneous" samples taken in the Selby "smoke zone."*

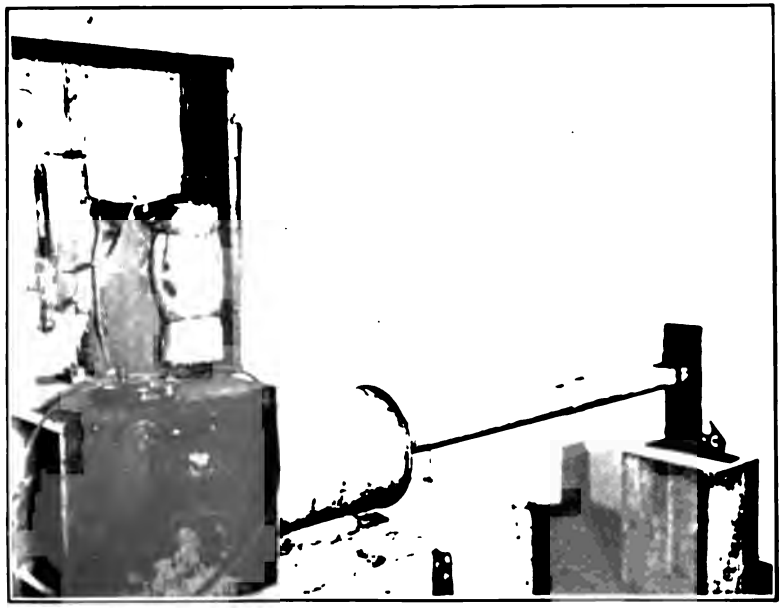
Month.	Number of tests.	Proportion of total.
1913.		*Per cent.*
September	232	4.8
October	1,216	25.0
November	1,069	22.0
1914.		
March	386	7.9
April	1,216	25.0
May	743	15.3
Total	4,862	.....

Samples were taken between the hours of 4.00 a. m. and 6.00 p. m., as shown below:

Hours at which "instantaneous" samples were taken.

Hours	Number of samples.	Proportion of total.
		Per cent.
4 a. m. to 8 a. m.	179	3.7
8 a. m. to 12 m.	2,140	44.0
12 m. to 6 p. m.	2,543	52.3
Total	4,862	.....

A. VIEW TOWARD WEST ALONG THE STRAITS FROM STATION 1.



B. APPARATUS FOR GETTING KNOWN MIXTURES OF SULPHUR DIOXIDE AND AIR.

Of the total 4,862 samples 3,663 (75.35 per cent) were found to contain less sulphur dioxide than the equivalent of one-tenth of a cubic centimeter of N/500 iodine solution, which was the limit of the sensibility of the analytical method used. In calculating the average sulphur dioxide content of the 4,862 samples, these samples were assumed to contain one-half the smallest quantity that could be determined by titration, as stated above. The average analysis of the 4,862 samples, calculating the 3,663 in the above manner, was 0.22 part SO_2 per million parts of air. Were these 3,663 samples assumed to contain no sulphur dioxide at all, the average analysis of the 4,862 samples would be 0.15 part SO_2 per million of air. In the following table is shown the number of samples containing sulphur dioxide between certain limits:

TABLE 8.—*Number of "instantaneous" samples that contained different amounts of SO_2 content.*

Limits of concentration (parts of SO_2 per million).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	3,663	75.35
.2 to .4	531	10.91
.4 to 6	322	6.61
.6 to .8	155	3.19
.8 to 1.0	69	1.42
1.0 to 1.5	66	1.37
1.5 to 2.0	35	.72
2.0 to 2.5	12	.25
2.5 to 3.0	3	.06
3.0 to 4.0	2	.04
4.0 to 5.0	2	.04
5.0 to 7.0	2	.04
	4,862	.....

Thus, of the total number of "instantaneous" samples taken in the Selby smoke zone during the months of September, October, and November, 1913, and March, April, and May, 1914, 75.35 per cent contained less than 0.2 part SO_2 per million parts air; 86.26 per cent contained less than 0.4 part SO_2 per million parts air, and 97.46 per cent contained less than 1.0 part SO_2 per million parts air. Only 21 samples, or 0.43 per cent, contained more than 2 parts SO_2, and no sample analyzed more than 7.1 parts SO_2 per million. In order to set forth this vast amount of analytical data in such a manner that the salient features can be studied readily, these results have been separated into two major divisions and the divisions further subdivided, as follows:

Outline of method of presenting data regarding "instantaneous" samples.

A. Determinations made inside city limits of Benicia.
  1. General summary.
  2. Summary of determinations made during definite periods of time.
  3. Summary of determinations made under different wind conditions.
  4. Summary of determinations made within the following limits of areas.
    (*a*) Station 1.
    (*b*) Vallejo-Benicia road, between shipyard and city limits near Carty's.
    (*c*) North of Vallejo-Benicia road, between Burke's saloon and shipyard.
    (*d*) Residential portion of Benicia, east of Burke's saloon, including hills north of K Street and east to arsenal.
    (*e*) Business section of Benicia south of J Street.

B. Determinations made in the agricultural district west or northwest of Benicia, between Benicia and Vallejo.
  1. General summary.
  2. Summary of determinations made during definite periods of time.
  3. Summary of determinations made under different wind conditions.
  4. Summary of determinations made within the following locations:
    (*a*) Station 2.
    (*b*) Coves west of station 2, comprising Glen, Elliott, and Dos Reis Coves.
    (*c*) Vallejo-Benicia road, between city limits and Carquinez cemetery.
    (*d*) Vallejo-Benicia road between Carquinez cemetery and Vallejo city limits.

DETAILED RESULTS OF DETERMINATIONS MADE INSIDE CITY LIMITS OF BENICIA.

GENERAL SUMMARY.

Total number of samples, 2,841.

Average sulphur dioxide content of samples 0.20 part per million parts of air.

Maximum concentration found, 2.4 parts SO_2 per million parts of air.

Range of results—

Range of results of determinations of SO_2 within city limits of Benicia.

Limits of concentration (parts SO_2 per million).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	2,129	75.00
0.2 to 0.4	386	13.56
0.4 to 0.6	197	6.92
0.6 to 0.8	80	2.80
0.8 to 1.0	27	.95
1.0 to 1.5	16	.56
1.5 to 2.0	5	.17
2.0 to 2.5	1	.04
	2,841	100.00

Thus, 75 per cent of the samples contained less than 0.2 part SO_2 per million parts air; 88.56 per cent less than 0.4 part SO_2 per million parts air; and 99.23 per cent contained less than 1.0 part SO_2 per million. Only 1 sample of the 2,841 contained more than 2.0 parts SO_2 per million parts of air.

SUMMARY OF DETERMINATIONS MADE WITHIN DEFINITE TIME PERIODS.

A summary of the determinations made within definite periods of time follows:

Summary of determinations made within definite time periods, city limits of Benicia.

Month or time.	Number of determinations.	Proportion of total.	Parts SO_2 per million parts air.	
			Average.	Maximum.
		Per cent.		
September	85	3.0	0.50	1.70
October	732	25.8	< .20	2.40
November	704	24.8	< .20	1.00
March	180	6.3	< .20	1.00
April	654	23.0	.25	1.00
May	486	17.1	.30	1.25
	2,841	100.0	.....	.....
4 a. m. to 8 a. m.	136	4.8	< .20	.65
8 a. m. to 12 m.	1,300	45.7	.20	1.00
12 m. to 6 p. m.	1,405	49.5	.22	2.40

SUMMARY OF DETERMINATIONS MADE UNDER DIFFERENT WIND CONDITIONS.

A summary of determinations made under different wind conditions follows:

Summary of determinations made under different wind conditions.[a]

Condition of wind.	Number of determinations.	Proportion of total.	Parts SO_2 per million parts air.	
			Average.	Maximum.
		Per cent.		
Slight west wind or calm	577	20.3	0.30	2.40
Moderate or high west wind	836	29.4	.27	1.25
South or southwest wind	405	14.3	< .20	.80
East or southeast wind	398	14.0	< .20	.80
North or northeast wind	173	6.1	< .20	.40
Northwest wind	452	15.9	< .20	.60
	2,841	.....	.....	.....

[a] In segregating the data the local wind conditions as recorded at the place of sampling were used.

SUMMARY OF DETERMINATIONS MADE WITHIN CERTAIN DEFINITE AREAS.

Summary of determinations made within certain definite areas.

Place of taking sample.	Number of samples taken.	Proportion of total.	Parts SO_2 per million parts air.	
			Average.	Maximum.
		Per cent.		
Station 1	1,989	70.1	0.22	2.40
Vallejo-Benicia road between shipyard and city limits	339	11.9	.20	1.25
North of Vallejo-Benicia road, between Burke's saloon and shipyard	89	3.1	.23	1.10
Residential section east of Burke's saloon to arsenal, including hills north of K Street	242	8.5	.20	1.70
Business section of Benicia south of J Street	182	6.4	< .20	1.00
	2,841	.....	.....	.....

GENERAL DISCUSSION OF THE RESULTS OBTAINED INSIDE THE CITY LIMITS OF BENICIA.

Samples of air taken when the wind was from a direction other than west occasionally contained determinable quantities of sulphur dioxide. The average content of these samples, however, was less than 0.2 part SO_2 per million parts air, and the maximum was 0.8 part SO_2 per million. This value was obtained when the wind was from the east or southeast, and undoubtedly contained SO_2 from the smelter of the Mountain Copper Co. at Martinez.

Samples taken when the wind was from the west generally contained determinable amounts of sulphur dioxide. The highest concentration (2.4 parts SO_2 per million) was found in a sample taken at station 1, when the wind conditions were such that the smoke was drifted over the station with apparently the least amount of diffusion or dispersion. The samples containing more than 1 part SO_2 per million were, with three exceptions, all taken along the water front between the shipyard and the end of G Street. The three exceptions were taken near the Dana place, one-half mile north of the Vallejo-Benecia Road, on September 27.

The samples taken in the residential section east of Burke's saloon and north of G Street all contained less than 1 part SO_2 per million. In the business portion of the town, south of G Street, the smallest concentrations were found.

The highest concentrations were found during the times when there was a very light west wind or an almost calm, causing the Selby smoke to drift in puffs or pockets along the straits directly to Benicia. Under these very unfavorable conditions, the maximum concentration found was 2.4 parts SO_2 per million, and 22 samples of the 577 taken

under these conditions contained more than 1 part SO_2 per million of air.

With a moderate or brisk west wind, the sulphur dioxide was so well diluted by the time the smoke reached Benicia that no high concentrations were found. Even under the maximum sulphur output from the smelter, the highest concentration was not more than 1.25 parts SO_2 per million.

DETERMINATIONS MADE IN AGRICULTURAL DISTRICT WEST AND NORTHWEST OF BENICIA, BETWEEN BENICIA AND VALLEJO.

GENERAL SUMMARY.

Total number of samples, 2,021.

Average sulphur dioxide content of samples 0.24 part SO_2 per million parts air.

Maximum concentration, 7 to 7.1 parts SO_2 per million parts air.

Range of results—

Range of results of determinations of SO_2 in agricultural district west and northwest of Benicia, between Benicia and Vallejo.[a]

Limits of concentration (parts SO_2 per million).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	1,534	75.80
.2 to .4	145	7.20
.4 to .6	125	6.20
.6 to .8	75	3.70
.8 to 1.0	42	2.10
1.0 to 1.5	50	2.50
1.5 to 2.0	30	1.50
2.0 to 2.5	11	.55
2.5 to 3.0	3	.15
3.0 to 4.0	2	.10
4.0 to 5.0	2	.10
5.0 to 6.0	1	.05
6.0 to 7.0	1	.05
	2,021	100.00

[a] Several of the determinations giving results higher than 3 parts SO_2 per million have been multiplied by the factor 1.2 to correct for analytical errors of the original method.

Thus 75.8 per cent of the total number of samples taken in the agricultural district contained less than 0.2 part SO_2 per million parts air; 83 per cent less than 0.4 part SO_2 per million parts air; and 95 per cent of the total number contained less than 1 part SO_2 per million parts air. Twenty samples contained more than 2 parts SO_2 per million. The maximum concentration was 7.1 parts SO_2 per million.

SUMMARY OF DETERMINATIONS MADE WITHIN DIFFERENT TIME PERIODS.

A summary of determinations made within different time periods follows:

Summary of SO_2 determinations made within different time periods.[a]

Month or time.	Number of determinations.	Proportion of total.	Parts SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
September	147	7.3	0.75	3.0
October	484	24.0	.35	7.1
November	365	18.0	< .20	1.8
March	206	10.2	< .20	0.2
April	562	27.8	< .20	1.0
May	257	12.7	.25	3.2
	2,021	100.0	.....	.....
4 a. m. to 8 a. m.	43	2.1	.20	0.6
8 a. m. to 12 m.	840	41.6	.23	7.1
12 m. to 6 p. m.	1,138	56.3	.26	5.5
	2,021	100.0	.....	.....

[a] The samples taken at this point (the agricultural district) during September averaged higher than during the following months. In September the samples were taken only when the smoke from Selby was blown generally to this point.

SUMMARY OF DETERMINATIONS MADE UNDER VARIOUS WIND CONDITIONS.

In segregating data according to the wind conditions existing at the time the samples were taken, the following subdivisions have been used:

1. Slight west wind or almost calm. Smoke drifting or blown gently along lines included in the angle COD, or along line OED. (Pl. VI.)
2. Smoke blown along same lines as above but under strong or moderate wind.
3. Smoke blown along straits or on Contra Costa shore, along lines indicated in angle AOC (Pl. VI). Wind direct from west or slightly north of west.
4. Wind from south or southwest blowing smoke along path of angle EOF (Pl. VI).
5. Wind from southeast or east.
6. Wind from northeast or north.

Summary of results of SO_2 determinations made under various wind conditions.[a]

Condition of wind.	Number of samples.	Proportion of total.	Parts SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Slightly west. Smoke in path COD or OED.[b]	300	14.9	0.90	7.10
Strong or moderate west. Smoke in path COD or OED.[b]	186	9.2	.45	1.15
Smoke in path COA.[b] West or northwest wind	787	38.9	< .20	.95
South or southwest wind	288	14.3	< .20	1.00
East or southeast	316	15.6	< .20	.20
North or northeast	144	7.1	< .20	< .20
	2,021	100.0	.24	.....

[a] In segregating the data the local wind conditions as recorded at place of sampling were used.
[b] Letters refer to Plate VI.

DETERMINATIONS MADE WITHIN CERTAIN DEFINITE AREAS.

The results of determinations made within certain definite areas were as follows:

Results of SO_2 determinations made within certain definite areas.

Place of sampling.	Number of samples.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Station 2 at White's	1,773	87.7	0.25	7.10
Coves, west of station 2, Glen, Elliot, and Dos Reis	95	4.7	.20	2.25
Vallejo-Benicia road between city limits and Carquinez cemetery	111	5.5	.27	2.60
Vallejo-Benicia road between Carquinez cemetery and Vallejo city limits	42	2.1	< .20	1.00
	2,121	100.0	.24	7.10

GENERAL DISCUSSION OF RESULTS OBTAINED IN AGRICULTURAL DISTRICT NORTH OR NORTHWEST OF BENICIA.

When the wind was from the east, southeast, north, or northeast, the amount of sulphur dioxide in the atmosphere was not determinable by the method employed for the instantaneous samples.

As was expected, the greatest sulphur dioxide contamination was found during the times that the Selby smoke was blown gently or drifted along the paths COD or OED. (Pl. VI.) Under these conditions the smoke at times became rather dense along the bluffs north of the straits, and the sulphur dioxide concentration of the atmosphere in that portion of the agricultural district averaged 0.90 part SO_2 per million parts of air. On four occasions the sulphur dioxide could be detected by smell, and samples taken during these occasions contained between 3 and 7 parts SO_2 per million parts of air.

The determinations and observations made at station 2 checked the statements made by many of the residents of the district and confirmed our conclusions that this station was located in a place where the greatest contamination in the agricultural district would be found. The sulphur dioxide concentrations found at this point on several occasions were comparatively very high.

These high concentrations were obtained when puffs of smoke drifted along past the station. Only at one time did the concentrations remain high for more than a few minutes at a time, as will be shown later.

In the agricultural district along the road between the Benicia city limits and Carquinez cemetery the concentration was found to be above 1 part SO_2 per million only on one afternoon, September 30, when the right wind condition existed to carry puffs of smoke with about 2 parts SO_2 per million over to the land of Manuel Brazil. Between the Carquinez cemetery and the Vallejo city limits only the slightest traces of SO_2 were ever found.

DETAILED RESULTS OF DETERMINATIONS.

METHOD OF CLASSIFYING DETAILS.

In the following pages the determinations, summarized above, will be segregated according to the location of the sampling point as previously outlined, and the details of each segregation will be discussed rather fully. This detailed discussion will be according to the following outline:

1. General summary.
2. Summary of determinations made during definite periods of time.
3. Summary of determinations made under different wind conditions.
4. Details of daily tests, segregated according to wind conditions.
5. Details of determinations made under most unfavorable wind and smoke conditions.

DETAILS OF DETERMINATIONS AT STATION 1.[a]

Determinations made as follows:

Month.	Year.	Investigator.
September	1913	A. E. Wells and G. N. Libby.
October	1913	A. E. Wells and J. D. Enas.
November	1913	A. E. Wells and J. D. Enas.
March	1914	J. D. Enas.
April	1914	J. D. Enas and R. W. Noreen.
May	1914	J. D. Enas and R. W. Noreen.

[a] See Plate VI.

GENERAL SUMMARY.

Total number of samples, 1,989.

Average sulphur dioxide content of samples, 0.22 part SO_2 per million parts of air.

Maximum sulphur dioxide content of samples, 2.40 parts SO_2 per million parts of air.

Range of results—

Range of results of determinations at station 1.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	1,464	73.60
.2 to .4	308	15.50
.4 to .6	141	7.10
.6 to .8	48	2.40
.8 to 1.0	18	.90
1.0 to 1.5	6	.30
1.5 to 2.0	3	.15
2.0 to 2.5	1	.05
	1,989	.....

Thus, of the 1,989 samples taken at station 1, the point where was found the maximum contamination of the air of Benicia, due to the Selby smelter, 1,464, or 73.6 per cent, contained less than 0.2 part SO_2 per million parts of air; 1,772, or 89.1 per cent, contained less than 0.4 part SO_2 per million parts of air; and 1,979, or 99.5 per cent contained less than 1.0 part SO_2 per million.

SUMMARY OF DETERMINATIONS MADE DURING DEFINITE PERIODS OF TIME.

A summary of determinations made during definite periods of time follows:

Summary of SO_2 determinations during various periods of time.

Month or time.	Number.	Proportion of total.	Parts SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
September [a]	34	1.7	0.43	1.15
October	416	20.9	< .20	2.40
November	511	25.7	< .20	.90
March	180	9.1	< .20	1.00
April	553	27.8	.25	.90
May	295	14.8	.30	1.00
	1,989	100.0	.....	.....
4 a. m. to 8 a. m.	101	5.1	.20	.60
8 a. m. to 12 m.	915	46.1	.20	1.00
12 m. to 6 p. m.	973	48.8	.25	2.40
	1,989	100.0	.....	.....

[a] The tests in September were made only at times when the wind was blowing the Selby smoke directly to station 1. This explains why the average for September is higher than for the other months, which include the determinations made under all wind conditions.

SUMMARY OF DETERMINATIONS MADE UNDER VARIOUS WIND CONDITIONS.

Following is a summary of determinations made during various wind conditions:

Summary of SO_2 determinations during various wind conditions.

Condition of wind.	Number of determinations.	Proportion of total.	Parts SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Slight west or almost calm	306	15.4	0.35	2.40
Moderate or brisk west wind	585	29.5	.25	1.00
South or southwest	304	15.3	< .20	.40
East or southeast	283	14.2	< .20	.80
North or northeast	162	8.1	< .20	.40
Northwest wind	349	17.5	< .20	.60
	1,989	100.0	.....	.....

DETAILS OF DAILY TESTS, SEGREGATED ACCORDING TO WIND CONDITIONS.

The following tables give the average and the maximum sulphur dioxide content of the samples taken under the different wind conditions on different days. In the tables giving the data for slight west wind and for moderate or brisk west wind conditions, the rate of sulphur elimination from the Selby plant is also given.

Details of 306 determinations made at station 1, when there was a slight west wind.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1914.				*Tons.*
Sept. 17	18	0.60	1.15	30	Apr. 6	5	0.30	0.40	28
Oct. 10	5	1.00	2.40	21	7	16	.50	.80	27
16	19	< .20	.20	2	8	23	.20	.40	32
17	24	< .20	.20	18	11	13	< .20	.40	28
20	7	.75	1.60	8	13	21	.20	.40	27
27	28	.50	1.90	40	14	20	.30	.80	20
28	27	.40	1.50	40	17	4	.70	.80	21
Nov. 10	14	.50	.90	33	21	1	.20	.20	23
					27	7	.60	.80	25
1914.					May 1	4	.40	.60	27
Mar. 20	5	< .20	.40	24	10	16	.40	.60	38
25	18	.30	1.00	31					
27	6	.25	.40	28		306	.35	.....	.....
2	5	.50	.60	23					

Details of 585 determinations made at station 1, when there was a moderate or brisk west wind.

Date.	Number of tests.	Parts of SO_2 per million parts of air		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1914.				*Tons.*
Sept. 24	16	0.25	0.4	22	Apr. 3	8	0.25	0.4	27
Oct. 12	2	< .20	.2	29	5	16	< .20	.2	23
13	5	.30	.4	14	6	12	< .20	.4	28
14	7	< .20	.2	16	10	13	.25	.6	27
15	4	.40	.8	14	15	15	.25	.8	16
21	4	.20	.3	16	16	10	.40	.8	16
22	24	< .20	.2	11	19	2	.40	.4	26
23	19	< .20	.2	12	20	11	.20	.4	27
29	25	.20	.8	38	22	13	.50	1.0	21
30	5	.40	.8	16	23	12	.35	.6	33
31	23	< .20	.2	11	24	18	.40	.6	28
Nov. 2	10	.30	.4	10	25	18	.35	.6	29
3	19	< .20	.6	19	26	19	.45	.6	27
6	10	< .20	.3	11	27	11	.50	.8	25
15	10	.30	.9	16	28	10	.50	.8	21
16	13	.20	.6	14	May 1	5	.30	.6	27
21	8	.30	.4	35	2	10	.35	.4	25
22	16	.20	.5	36	3	18	.65	1.0	26
28	9	< .20	.2	0	5	12	.50	.8	29
29	6	< .20	.2	40	6	5	.70	.8	41
					7	22	.50	.7	40
1914.					8	17	.30	.6	36
Mar. 21	9	.30	.5	31	9	13	.35	.8	25
22	11	< .20	.4	31	11	6	.40	.6	45
26	17	.20	.4	22					
27	17	.25	.4	28		585	.25	.....	.....

Details of 304 determinations made at station 1, when the wind was from the south or southwest.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Date.	Number of tests.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.			Average.	Maximum.
1913.				1914.			
Oct. 13	13	<0.20	<0.20	Apr. 10	7	<0.20	0.20
Oct. 14	9	< .20	< .20	Apr. 17	1	.40	.40
Oct. 25	14	< .20	< .20	Apr. 20	13	< .20	.20
Nov. 1	10	< .20	< .20	Apr. 21	3	< .20	.20
Nov. 10	8	< .20	< .20	Apr. 22	9	.20	.40
				Apr. 23	8	.20	.40
1914.				May 4	20	< .20	.40
Mar. 23	8	.20	.60	May 6	9	.30	.40
Mar. 24	22	< .20	.60	May 8	3	< .20	.20
Mar. 25	6	< .20	.60	May 10	6	< .20	.20
Mar. 26	3	< .20	.20	May 11	8	< .20	.40
Mar. 28	15	.20	.40	May 13	22	< .20	.40
Mar. 31	16	< .20	.20	May 14	20	< .20	.20
Apr. 3	12	< .20	.20				
Apr. 4	15	< .20	< .20		304	< .20	.....
Apr. 9	24	< .20	.20				

Details of 283 determinations made at station 1, when the wind was from the east or southeast.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Date.	Number of tests.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.			Average.	Maximum.
1913.				1914.			
Oct. 26	16	<0.20	<0.20	Mar. 23	4	<0.20	<0.20
Nov. 4	21	< .20	< .20	Mar. 30	9	< .20	.40
Nov. 5	25	< .20	< .20	Apr. 2	16	< .20	.80
Nov. 6	10	< .20	< .20	Apr. 17	9	.20	.25
Nov. 7	29	< .20	.30	Apr. 18	12	< .20	< .25
Nov. 11	13	< .20	< .20	Apr. 21	15	< .20	< .25
Nov. 13	7	< .20	< .20	May 9	9	< .20	.20
Nov. 17	12	< .20	< .20				
Nov. 18	5	< .20	< .20		283	< .20	.....
Nov. 24	19	< .20	< .20				
Nov. 25	15	< .20	< .20				
Nov. 26	17	< .20	< .20				
Nov. 28	10	< .20	< .20				

Details of 162 determinations made at station 1, when there was a north or northeast wind.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Date.	Number of tests.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.			Average.	Maximum.
1913.				1914.			
Oct. 11	21	<0.20	0.40	Mar. 17	11	<0.20	<0.20
Oct. 18	19	< .20	< .20	Mar. 23	3	< .20	< .20
Oct. 20	17	< .20	< .20	Apr. 1	16	< .20	.20
Nov. 8	18	< .20	< .20	Apr. 11	3	< .20	< .20
Nov. 13	7	< .20	< .20	Apr. 18	4	< .20	< .20
Nov. 14	18	< .20	< .20	Apr. 21	1	< .20	< .20
Dec. 1 and 3	24	< .20	< .20				
					162	< .20	.....

Details of 349 determinations made at station 1, when the wind was north of west.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Date.	Number of tests.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.			Average.	Maximum.
1913.				1914.			
Oct. 12	12	<0.20	<0.20	Apr. 19	16	<0.20	0.20
Oct. 14	15	< .20	< .20	Apr. 21	1	< .20	< .20
Oct. 15	20	< .20	< .20	Apr. 23	2	< .20	.40
Oct. 21	20	< .20	< .20	Apr. 25	1	< .20	< .20
Oct. 24	16	< .20	< .20	Apr. 27	5	.25	.40
Oct. 30	19	< .20	< .20	Apr. 28	11	.30	.40
Nov. 2	8	< .20	.20	Apr. 29	18	< .20	< .20
Nov. 3	4	< .20	.20	Apr. 30	13	< .20	< .20
Nov. 6	14	< .20	.30	May 1	14	.25	.40
Nov. 15	18	< .20	.30	May 2	10	< .20	.40
Nov. 19	24	< .20	< .20	May 5	6	.50	.60
Nov. 20	9	< .20	< .20	May 6	4	.50	.60
Nov. 21	15	< .20	< .20	May 8	3	.50	.60
Nov. 29	5	< .20	< .20	May 11	11	< .20	.40
				May 12	22	.20	.40
1914.							
Apr. 16	9	< .20	.20		349	< .20	.....
Apr. 17	6	< .20	.20				

DETAILS OF DETERMINATIONS MADE UNDER MOST UNFAVORABLE WIND AND SMOKE CONDITIONS.

In the following pages are given the individual tests made on certain days when the smoke conditions apparently were the worst for Benicia. There was only a slight drift of air from the west, and the smoke could be seen floating along the straits directly to Benicia. It is difficult to believe that, with the same amount of sulphur dioxide coming from the smelter stack, the concentrations of sulphur dioxide in the air at Benicia could be greater than those found as shown below.

SEPTEMBER 17, 1913.

Smelter data.

Number sintering machines in operation, 3.
Rate of sulphur elimination, 30 tons per 24 hours.
Wind record at smelter, calm or slight southwest.

Station 1 data.[a]

Tabulated data for station 1 follow.

Results of SO_2 determinations at station 1, Sept. 17, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
p. m.		
1.45	0.8	Light west wind; smoke coming direct from smelter to station; very hazy and smoky around station. Believe the wind and smoke condition the worst possible for the sulphur output.
1.55	.3	
2.05	.8	
2.15	.5	
2.30	.5	
3.00	.5	
3.10	.5	
3.25	.4	
3.40	.6	
3.50	.4	
4.30	.9	At 5.30 a little breeze came up from the west, clearing the air somewhat.
5.15	1.1	
5.25	1.0	
5.35	.9	
5.45	.6	
5.55	.5	
6.10	.3	
6.30	.3	

OCTOBER 10, 1913.

Smelter data.

Number sintering machines in operation, 2.
Rate of sulphur elimination, 21 tons per 24 hours.
Wind record at smelter, calm.

[a] Determinations made by A. E. Wells and G. N. Libby. During the time these tests were being made the air was very hazy and smoky. It was not possible to see across the straits to Port Costa. Mr. J. C. Fisher claimed that it was a very bad "smelter day" and that between 2 and 2.30 p. m. he could smell the smoke. Could not detect the smell myself. The haze and smoke was general and was not confined to the Selby "smoke zone."—A. E. Wells.

Station 1 data.[a]

Tabulated data for station 1 follow.

Results of SO_2 determinations at station 1, Oct. 10, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
p. m.		
2.45.....	2.4	Calm. Dense haze and smoke drifting in from the west direct to station. No odor of SO_2.
3.00.....	1.5	Clearing a little at the station, but very hazy all along the straits.
3.15.....	.3	Clearing all around; still very calm. No perceptible change in the velocity or direction of the wind.
4.00.....	.4	Clearer.
4.15.....	.4	Do.

October 20, 1913.

Smelter data.

Number of sintering machines in operation, 1.
Rate of sulphur elimination, 8 tons per day.
Wind record at smelter, calm.

Station 1 data.[b]

Following are tabulated data for station 1.

Results of SO_2 determinations at station 1, Oct. 20, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
p. m.		
3.10.....	0.8	Calm. Very slight drift from the west. Very smoky around station.
3.25.....	.6	
3.40.....	1.0	
4.00.....	1.6	
4.15.....	.9	
4.20.....	.2	Calm. Clearing around station.
4.30.....	.1	Calm, clear.

SPECIAL NOTE BY A. E. WELLS.—After 2.30 p. m. there was a very slight drift of air from the west. No perceptible change in direction and velocity at station 1 between 3 and 4.30 p. m., yet a decided change in SO_2 concentrations was found during that time.

October 27, 1913.

Smelter data.

Number of sintering machines in operation, 2.
Ropp roaster in operation.
Rate of sulphur elimination, 40 tons per 24 hours.
Wind record at smelter, calm.

[a] Determinations made by A. E. Wells.
[b] Determinations made by J. D. Enas.

Station 1 data.[a]

Following are tabulated data for station 1.

Results of SO_2 determinations at station 1, Oct. 27, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
7.55	0.2	Hazy light northwest wind.
8.50	.2	Do.
8.35	.2	Do.
8.50	.2	Do.
9.05	.4	Light west wind.
9.15	.2	Do.
9.45	.4	Do.
10.00	.2	Do.
10.25	.4	Do.
10.40	.3	Do.
10.55	.4	Do.
11.20	.3	Do.
11.35	.4	Do.
11.55	.2	Do.
p. m.		
12.15	.2	Do.
1.10	1.9	Smoke in the vicinity.
1.20	.4	Do.
1.40	1.9	Do.
2.15	1.2	Do.
2.30	.6	Do.
2.45	.2	Clearing.
3.00	.6	Smoky, strong oil smell.
3.10	.7	Do.
3.20	1.2	Do.
3.55	.6	Do.
4.15	.3	Do.
4.30	.2	Do.
4.45	.2	Do.

After 5 p. m. a moderate breeze came up, clearing the air.

SPECIAL NOTE BY A. E. WELLS.—During the morning the smoke lay very close to the Contra Costa shore, about noon began to drift out more nearly to the north side of the straits, and was noticed over station 1. At 1.30 p. m. the general wind was about the same, yet the smoke had cleared at station 1. The smoke again drifted in at 1.40 p. m. At 2 p. m. it was clear around station 1.

OCTOBER 28, 1913.

Smelter data.

Number of sintering machines in operation, 2.

Ropp roaster in operation.

Rate of sulphur elimination, 40 tons per 24 hours.

Wind record at the smelter, west and calm; maximum velocity, 6 miles per hour.

[a] Determinations made by J. D. Enas.

Station 1 data.[a]

Following are tabulated data for station 1:

Results of SO_2 determinations at station 1, Oct. 28, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.	
		Wind.	Smoke.
a. m.			
4.00	0.4	Calm	Slightly hazy.
4.15	.4		
4.30	.4		
4.45	.4	Slight west	
5.00	.4	do	
5.15	.4	do	
5.30	.2	do	
8.40	.2	do	Smoky along straits.
9.10	.2	do	Do.
9.25	.2	do	Do.
9.55	.2		
10.30	.1		
10.55	.2		
11.15	.6		
11.30	.6		Smoky along straits and in vicinity.
11.40	.5		Smoke spreading over vicinity.
11.50	.5		Do.
p. m.			
12.10	.3		
12.40	1.5		
1.00	.8		
1.10	.9		
1.30	.4		Smoke clearing up.
1.45	.2		
2.00	.2		
2.25	.2		Smoke spreading over station.
2.35	.2		
2.45	.2		Wind increasing in strength, clearing the air.

NOTE BY A. E. WELLS.—About noon the smoke was visible drifting over Benicia. Appeared densest around station 1. Cleared up by 1.15 p. m.

MAY 10, 1914.

Smelter data.

Number of sintering machines, 3.
Ropp roaster in operation.
Rate of sulphur elimination, 38 tons per 24 hours.
Wind, west; velocity, 3 miles per hour.

[a] Determinations made by J. D. Enas.

Station 1 data.

Tabulated data for station 1 follow.

Results of SO_2 determinations at station 1, May 10, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
6.50	0.6	Direct west wind; clear.
7.25	.4	Light west wind; clear.
7.40	.4	Do.
7.50	.4	Do.
8.25	.4	Do.
8.40	.4	Do.
8.50	.4	Do.
9.25	.6	Do.
9.40	.4	Do.
9.50	.4	Do.
10.20	.4	Do.
10.35	.4	Do.
10.50	.4	Do.
11.20	.2	Light south of west wind; clear.
11.35	.2	Do.
11.50	.4	Light western breeze; clear.
p. m.		
1.20	<.2	Light south breeze; clear.
1.45	<.2	Do.
2.20	<.2	Do.
2.45	<.2	Light south of west breeze; clear.
3.25	.4	Light west wind; clear.
3.50	.4	Do.

GENERAL COMMENTS.

An interesting and significant illustration of the conditions in the Selby "smoke zone" is shown from the results obtained during light west wind conditions. Even under fairly constant general wind conditions the average and maximum contamination of the air at a point situated at station 1, 4½ miles from the smelter, is not always proportional to the sulphur dioxide output from the smelter. As an example of this feature, compare the determinations made on September 17, October 10, 17, 20, and 27, when the general wind conditions were almost identical.

Examples of disagreement between variations in air contamination and variations in sulphur output from smelter.

Date.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
	Average.	Maximum.	
1913.			*Tons.*
Oct. 16	<0.20	0.20	2
Oct. 20	.75	1.60	8
Oct. 17	<.20	.20	18
Oct. 10	1.00	2.40	21
Apr. 21	.20	.20	23
Sept. 17	.60	1.15	30
Oct. 27	.50	1.90	40

Thus, on the 10th of October, when the smelter was turning out sulphur dioxide at the rate of 42 tons per day, the concentration reached 2.4 parts SO_2 per million parts of air at station 1, as against

a maximum of 0.4 part SO_2 per million parts of air found on April 21, when the wind conditions were about the same and the smelter output was a little greater. The wide difference in sulphur dioxide concentration under nearly the same general wind conditions and the same output of sulphur dioxide from the smelter shows the great influence of slight and local wind changes or other atmospheric conditions.

At no time during the investigations was there a continuous drift of air carrying more than 1 part SO_2 per million parts of air past the station for more than a few minutes at a time. Only when there were puffs of smoke passing was the sulphur dioxide content of the air raised appreciably. Whenever the wind was above a slight breeze or drift these puffs were dispersed and dissipated, so that no high concentrations were present.

From these "instantaneous" samples it is not possible to state definitely how long any certain concentration was present at any time. It will be noted from the above data that the highest concentrations were only in isolated samples. No case of continuous high concentrations (over 1 part SO_2 per million parts of air) lasting more than the time between the taking of two consecutive samples, about 20 minutes, was recorded. The following figures have been prepared to show the approximate length of time that concentrations above 0.5 part SO_2 per million parts of air existed during any day:

Approximate length of time certain concentrations of SO_2 were present in the air at station 1, with a west wind.

Number of parts of SO_2 per million parts of air.	Date.	Length of time.	Number of parts of SO_2 per million parts of air.	Date.	Length of time.
	1913.	*Minutes.*		1914.	*Minutes.*
2 to 2.5[a]	Oct. 10	[b] 5	More than 0.5	Mar. 25	60
				Apr. 2	120
More than 1	Sept. 17	60		Apr. 7	120
	Oct. 10	30		Apr. 10	20
	Oct. 20	15		Apr. 14	30
	Oct. 27	90		Apr. 15	30
	Oct. 28	15		Apr. 16	15
	May 10	15		Apr. 22	30
				Apr. 23	30
Total		[c] 225		Apr. 24	60
				Apr. 25	10
More than 0.5	Sept. 17	300		Apr. 26	60
	Oct. 10	30		Apr. 27	360
	Oct. 15	10		Apr. 28	180
	Oct. 20	75		May 1	10
	Oct. 27	180		May 3	360
	Oct. 28	90		May 5	270
	Oct. 29	10		May 6	150
	Oct. 30	20		May 7	240
	Nov. 10	45		May 8	60
	Nov. 15	15		May 10	30
			Total		[d] 3,020

[a] More than 2 and less than 2.5.
[b] Approximate.
[c] 225 minutes out of about 43,200 minutes of sampling time, or 0.5 per cent.
[d] 3,020 minutes out of 43,200 minutes of sampling time, or 7 per cent.

DETAILS OF DETERMINATIONS MADE ON THE VALLEJO-BENICIA ROAD, BETWEEN SHIPYARD AND BENICIA CITY LIMITS, NEAR CARTY'S PLACE.

GENERAL SUMMARY.

Total number of samples, 339.

Average sulphur dioxide content of samples, 0.2 part of SO_2 per million parts of air.

Maximum sulphur dioxide content, 1.25 parts of SO_2 per million parts of air.

Range of results of determinations made on Vallejo-Benicia road.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	261	76.9
.2 to .4	43	12.7
.4 to .6	24	7.1
.6 to .8	6	1.8
.8 to 1.0	4	1.2
1.0 to 1.5	1	.3
Total	339	100.0

DETAILED RESULTS.

Following are tabulations showing the results of SO_2 determinations:

Summary of determinations made at different time periods.

Month or time.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.		Investigator.
			Average.	Maximum.	
1913.		*Per cent.*			
September	7	2.1	0.35	0.6	A. E. Wells.
October	75	22.1	.20	.8	G. N. Libby.
November	38	11.2	.20	.4	Do.
1914.					
April	66	19.5	.25	.6	H. L. Long.
May	153	45.1	.25	1.25	Do.
Total	339	100.0			
4 a. m. to 8 a. m.	4	1.2	.50	.65	
8 a. m. to 12 m.	199	58.8	.20	.80	
12 m. to 6 p. m.	136	40.0	.20	1.25	
	339	100.0			

Summary of determinations made under various wind conditions.

Condition of wind.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Slight west wind	58	17.1	0.27	0.75
Moderate or high west wind	106	31.3	.30	1.25
South or southwest wind	75	22.1	< .20	.80
East or southeast wind	29	8.6	< .20	.30
North or northeast wind	.....	.....	.....	.....
Northwest wind	71	20.9	< .20	.40
	339	100.0	.....	.....

Details of determinations made on the Vallejo-Benicia road, between shipyard and city limits.

SLIGHT WEST WIND BLOWING.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.	
1913.				*Tons.*
Sept. 18	4	0.55	0.65	32
Oct. 4	4	.25	.40	12
Oct. 25	17	.25	.80	9
Nov. 8	8	.10	.40	11
1914.				
Apr. 3	6	< .20	< .20	27
Apr. 8	8	.30	.60	32
May 11	2	< .20	< .20	45
May 10	9	.40	.75	38
	58	.27	.....	.....

MODERATE OR BRISK WEST WIND BLOWING.

1913.				
Oct. 29	17	0.20	0.40	38
1914.				
Apr. 16	4	.50	.60	16
Apr. 25	11	.35	.60	29
May 2	14	.40	.80	25
May 3	20	.20	.50	26
May 4	20	.20	.60	28
May 9	13	.30	.75	25
May 12	7	.80	1.25	36
	106	.30	.....	.....

SOUTH OR SOUTH OF WEST WIND BLOWING.

1913.				
Oct. 6	15	<0.20	<0.20	.....
1914.				
Apr. 25	8	< .20	< .20	.....
Apr. 28	10	.40	.80	.....
May 8	6	.25	.25	.....
May 9	5	< .20	< .25	.....
May 12	13	< .20	< .25	.....
May 13	18	< .25	.25	.....
	75	< .20	.....	.....

Details of determinations made on the Vallejo-Benicia road, between shipyard and city limits—Continued.

EAST OR SOUTHEAST WIND BLOWING.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.	
1913.				*Tons.*
Nov. 14	12	<0.20	<0.20	.....
1914.				
Apr. 17	5	< .20	.20	.....
Apr. 21	8	< .25	.25	.....
May 10	4	< .20	< .20	.....
	20	< .20	.....	.....

NORTHWEST WIND BLOWING.

1913.				
Sept. 18	3	<0.20	0.25	.....
Oct. 4	8	< .20	< .20	.....
Oct. 10	9	< .20	< .20	.....
Oct. 24	16	< .20	.20	.....
Nov. 22	7	< .20	.20	.....
1914.				
Apr. 16	4	.25	.40	.....
Apr. 28	2	< .25	.25	.....
May 2	8	< .20	.25	.....
May 11	10	< .20	.25	.....
May 12	4	< .20	.25	.....
	71	< .20	.....	.....

NORTH OR NORTHEAST WIND BLOWING.

No determinations.

DETAILS OF DETERMINATIONS MADE UNDER MOST UNFAVORABLE WIND AND SMOKE CONDITIONS.

The data of September 18 and May 13, when the maximum concentrations were found, are given below:

SEPTEMBER 18, 1913.

Smelter data.

Number of sintering machines in operation, 3.
Rate of sulphur elimination, 32 tons per 24 hours.
Wind record at smelter, west and southwest, one-half mile per hour.

Sampling station data.

Tabulated data for the sampling station follow.

Results of determinations at sampling station on Vallejo-Benicia Road, September 18, 1913.[a]

Time.	Parts of SO_2 per million parts of air.[a]	Notes.
a. m.		
7.00	0.6	Very light west wind; hazy.
7.50	.5	Do.
8.15	.6	Do.
8.30	.5	Very light west and northwest wind; hazy.
8.40	.25	Very light northwest wind.
8.55	< .20	Do.
9.10	< .20	Do.

[a] Determinations made by A. E. Wells.

MAY 12, 1914.

Smelter data.

Number of sintering machines in operation, 3.
Ropp roaster in operation.
Rate of sulphur elimination, 38 tons per 24 hours.
Wind record at smelter, southwest, 4 to 5 miles per hour.

Results of determinations[a] at sampling station on Vallejo-Benicia Road, May 12, 1914.

Time.[b]	Parts of SO_2 per million parts of air.	Notes.
a. m.		
11.35	0.6	Moderate southwest wind.
11.45	.6	Do.
11.55	.8	Do.
p. m.		
12.10	1.0	Smoke coming past Dillon Point to station.
12.20	1.25	Do.
12.30	.8	Clearing at station.
12.45	.2	Clear at station.
1.00	.2	Southwest wind.

[a] Determinations by H. L. Long.
[b] Between 1.00 p. m. and 2.00 p. m. no samples were taken. After 2.00 p. m. the wind was from the southwest, and no sample carried more than 0.2 part of SO_2 per million parts of air.

DETAILS OF DETERMINATIONS MADE NORTH OF VALLEJO-BENICIA ROAD, BETWEEN BURKE'S SALOON AND THE SHIPYARD.

GENERAL SUMMARY.

Total number of samples, 89.

Average sulphur-dioxide content of samples, 0.23 part of SO_2 per million parts of air.

Maximum sulphur-dioxide content of samples, 1.10 parts of SO_2 per million parts of air.

Range of results—

Range of results of SO_2 determinations made north of Vallejo-Benicia Road.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	63	70.7
.2 to .4	4	4.5
.4 to .6	12	13.5
.6 to .8	4	4.5
.8 to 1.0	2	2.3
1.0 to 1.5	4	4.5
	89	100.0

DETAILED RESULTS.

Following are tabulations giving detailed results of determinations:

Summary of determinations made during definite periods of time.

Month or time.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
1913.				
September				
October	76	85.5	0.25	1.1
November	13	14.5	< .20	.2
1914.				
March				
April				
May				
Total	89	100.0		
4.00 a. m. to 8 a. m.	5	5.6	.30	.4
8.00 a. m. to 12 m.	43	48.3	.24	1.0
12.00 m. to 6 p. m.	41	46.1	.20	1.1
	89	100.0		

Details of determinations made under different wind conditions.

LIGHT WEST WIND BLOWING.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.	
				Tons.
Oct. 14	22	0.40	1.00	16
Oct. 16	21	< .20	.40	2
Oct. 27	20	.40	1.10	40
Nov. 4	13	< .20	.20	17
	76			

STRONG WEST WIND BLOWING.

No determinations made.

SOUTH, SOUTHWEST, NORTH, NORTHWEST, OR NORTHEAST WIND.

No determinations made.

EAST OR SOUTHEAST WIND BLOWING.

Oct. 31	13	<0.20	0.20	

DETAILS OF DETERMINATIONS MADE UNDER MOST UNFAVORABLE WIND AND SMOKE CONDITIONS.

The data obtained on October 27, when the maximum amount of sulphur dioxide in this series was found, are given below.

OCTOBER 27, 1913.

Place of sampling—near deserted farmhouse, in Dana place, about one-half mile north of Vallejo-Benicia Road.

Number of sintering machines in operation, 3.
Ropp roaster in operation.
Rate of sulphur elimination, 40 tons per day.
Wind record at smelter, calm.

Results of determinations made near deserted farmhouse in Dana place, about one-half mile north of Vallejo-Benicia Road.[a]

Time.	Parts of SO_2 per million parts of air.	Notes.
11.00 a. m. to 2.45 p. m...	<0.20	Light west wind.
3.00 p. m...	1.10	Smoke puffs drifting past.
3.20 p. m...	1.10	Do.
3.30 p. m...	.40	Do.
3.45 p. m...	< .20	Do.
4.05 p. m...	.80	Slight odor of SO_2.
4.15 p. m...	.70	Smoky in vicinity.
4.30 p. m...	1.00	Do.
4.35 p. m...	.70	Do.
4.50 p. m...	< .20	Clear.

[a] Determinations made by G. N. Libby.

DETAILS OF DETERMINATIONS MADE IN THE RESIDENTIAL PORTION OF BENICIA EAST OF BURKE'S SALOON, INCLUDING THE DISTRICT ON THE HILLS NORTH OF K STREET AND EAST TO ARSENAL.[a]

GENERAL SUMMARY.

Total number of samples, 242.

Average sulphur dioxide content of samples, 0.2 part of SO_2 per million parts of air.

Maximum sulphur dioxide content of samples, 1.7 parts of SO_2 per million parts of air.

Range of results—

Range of results of sampling in the residential portion of Benicia, east of Burke's saloon.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	182	75.2
.2 to .4	23	9.5
.4 to .6	13	5.4
.6 to .8	16	6.6
.8 to 1.0	1	.4
1.0 to 1.5	5	2.1
1.5 to 2.0	2	.8
	242	100.0

[a] September, October, and November determinations by G. N. Libby; May and April determinations by H. L. Long.

Summary of tests made during definite periods of time.

Month or time.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
September	44	18.2	0.60	1.70
October	131	54.1	.20	.60
November	45	18.6	< .20	.20
March	.....	.....	.....	.....
April	13	5.4	< .20	.20
May	9	3.7	.20	.25
	242	100.0	.....	.....
4 a. m. to 8 a. m.	20	8.3	.25	.60
8 a. m. to 12 m.	100	41.3	< .20	1.10
12 m. to 6 p. m.	122	50.4	.25	1.70
	242	100.0	.....	.....

Summary of determinations made under various wind conditions.

Direction of wind.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Slight west wind	94	38.8	0.20	1.7
Moderate or strong west wind	75	31.0	.35	1.1
South or southwest wind	18	7.4	< .20	.2
East or southeast wind	44	18.2	< .20	.2
North or northeast wind	11	4.6	< .20	.2
Northwest wind	.....	.....	.....	.....
	242	100.0	.....	.....

DETAILED RESULTS.

Detailed results follow.

Details of determinations made in the residential portions of Benicia, east from Burke's saloon, including the district on the hills north of K Street and east of the arsenal.

SLIGHT WEST WIND BLOWING.

Date.	Place of taking sample.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
			Average.	Maximum.	
1913.					*Tons.*
Sept. 25	Near Kuhlman's house, at end of G Street.	5	1.30	1.7	26
Oct. 7	Corner of K and Main Streets	2	.45	.5	12
Oct. 17	K Street, near Prince's residence	23	< .20	.4	18
Oct. 22	Hill near E. Selby's	18	< .20	.6	12
Oct. 23	U. S. Arsenal	17	< .20	.2	10
Oct. 28	Catholic cemetery	22	.20	.35	40
1914.					
Apr. 28	U. S. Arsenal	7	< .20	.2	21
		94	.20	.....	.....

Details of determinations made in the residential portions of Benecia, east from Burke's saloon, including the district on the hills north of K Street and east of the arsenal—Con.

MODERATE OR BRISK WEST WIND BLOWING.

Date.	Place of taking sample.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
			Average.	Maximum.	
1913.					Tons.
Sept. 25	Near Kuhlman's house, end of G Street.	16	0.70	1.0	26
Sept. 27	do	23	.30	1.1	18
Oct. 15	Near high school	9	.25	.4	14
Oct. 21	Near cemetery north of town	22	.20	.6	11
1914.					
May 12	On hill near Eben Selby's residence.	5	< .20	.25	38
		75			

SOUTH AND SOUTHWEST WIND BLOWING.[a]

Date.	Place.	Number of tests.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
1913.				
Oct. 7	K and Main Streets	13	<0.20	<0.20
Oct. 15	Near high school	5	< .20	< .20
		18		

EAST OR SOUTHEAST WIND BLOWING.

1913.				
Nov. 17	United States arsenal	5	<0.20	0.20
Nov. 25	do	13	< .20	.20
Nov. 26	do	16	< .20	.20
1914.				
Apr. 17	do	6	< .20	< .20
May 5	do	4	< .20	< .20
		44	< .20	

NORTH OR NORTHEAST WIND BLOWING.

1913.				
Nov. 8	K Street near Burke's saloon	11	<0.20	0.20

[a] When the wind was from the east and southeast the Mountain Copper smoke was sometimes headed toward Benicia, especially Army Point. However, as shown by the analyses of Nov. 17, 25, and 26, and Apr. 17 and May 5, no samples taken during those conditions contained more than 0.20 part SO_2 per million parts of air.

DETAILS OF DETERMINATIONS MADE UNDER MOST UNFAVORABLE WIND AND SMOKE CONDITIONS.

Details of the determinations made on September 25, when the highest concentrations of any samples included in this series were obtained, are given below:

SEPTEMBER 25, 1913.

Place of sampling, near residence of Mr. Kuhlman and Mr. Crooks, at end of G Street.

Number of sintering machines in operation, 3.

Rate of sulphur elimination, 28 tons per day.

Wind record at Selby—11 a. m., west, 2-mile velocity; 3 p. m., west, 10-mile velocity.

Results of samples taken at end of G Street.[a]

Time.	Parts of SO_2 per million parts of air.	Notes.	Time.	Parts of SO_2 per million parts of air.	Notes.
p. m.			*p. m.*		
12.30	1.0	Almost calm, slight drift from west; smoky.	2.55	0.6	Moderate west breeze; clear.
			3.10	.7	Do.
12.50	1.7	do	3.20	.6	Do.
1.15	1.3	do	3.40	1.0	Do.
1.30	1.7	do	4.05	.8	Do.
1.50	.7	Slight breeze from west; clearer.	4.15	.8	Do.
			4.25	.8	Do.
2.00	.6	Breeze blowing up briskly from west; clear.	4.35	.5	Do.
			4.50	.5	Do.
2.15	.6	Moderate west breeze; clear	5.00	.4	Do.
2.25	.6	do	5.20	.4	Do.
2.45	.4	do	5.45	.4	Do.

[a] Determinations made by A. E. Wells and G. N. Libby.

DETAILS OF DETERMINATIONS MADE IN THE BUSINESS SECTION OF BENICIA, SOUTH OF J STREET.

GENERAL SUMMARY.

Total number of samples, 182.

Average sulphur dioxide content of samples, less than 0.20 part of SO_2 per million parts of air.

Maximum sulphur dioxide content of samples <1 part of SO_2 per million parts of air.

Range of results -

Range of results of sampling in the business section of Benicia, south of J Street.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	159	87.4
.2 to .4	8	4.4
.4 to .6	7	3.8
.6 to .8	6	3.3
.8 to 1.0	2	1.1
	182	100.0

Summary of determinations made within certain time limits.

Month or time.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
September				
October	34	18.7	<0.20	0.6
November	97	53.3	< .20	.7
March				
April	22	12.1	< .20	.4
May	29	15.9	.30	1.0
	182	100.0		
4 a. m. to 8 a. m	6	3.3	< .20	.2
8 a. m to 12 m	43	23.6	< .20	1.0
12 m. to 6 p. m	133	73.1	< .20	.7
	182	100.0		

DETAILS OF DAILY TESTS SEGREGATED ACCORDING TO WIND CONDITIONS.

The details of daily tests segregated according to wind conditions are tabulated below.

Details of daily tests segregated according to wind conditions.

SLIGHT WEST WIND BLOWING.

Date.	Place of sampling.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
			Average.	Maximum.	
1913.					*Tons.*
Oct. 20	City wharf	13	<0.20	0.6	8
Nov. 9	Anderson Hotel	2	.60	.6	11
Nov. 21	do	18	< .20	.4	35
Nov. 22	K. & S. Tannery	10	< .20	.7	36
		43	< .20		

BRISK OR MODERATE WEST WIND BLOWING.

1913.					
Oct. 8	Anderson Hotel	4	<0.20	0.4	11
Oct. 9	do	17	< .20	< .2	11
Nov. 19	One block south of Anderson Hotel.	18	< .20	.2	16
1914.					
Apr. 16	Anderson Hotel	6	< .20	.2	18
Apr. 25	do	6	.20	.4	29
Apr. 28	do	4	< .20	.2	21
May 2	do	10	< .20	.4	24
May 11	do	5	.80	1.0	45
		70	< .20		

SOUTH OR SOUTHWEST WIND BLOWING.

1913.					
Nov. 9	Anderson Hotel	8	<0.20	0.2	

Details of daily tests segregated according to wind conditions—Continued.

EAST OR SOUTHEAST WIND BLOWING.

Date.	Place of sampling.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
			Average.	Maximum.	
1913.					*Tons.*
Nov. 7	City wharf	23	0.20	0.8	.....
1914.					
Apr. 17	Anderson Hotel	6	< .20	.2	.....
		29	.....	.....	.....

NORTHWEST WIND BLOWING.

1913.					
Nov. 20	City wharf	18	<0.20	0.2	.....
1914.					
May 11	Anderson Hotel	4	.25	.5	.....
May 12	do	10	< .25	.5	.....
		32	.....	.....	.....

DETAILS OF DETERMINATIONS AT STATION 2.

GENERAL SUMMARY.

Total number of samples, 1,773.

Average sulphur dioxide content of samples, 0.25 part SO_2 per million parts air.

Maximum sulphur dioxide content of samples, 7.1 parts SO_2 per million parts air.

Range of results—

Range of results of determinations at station 2.

Limits of concentration (parts of SO_2 per million parts of air.	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	1,334	75.30
.2 to .4	130	7.32
.4 to .6	109	6.12
.6 to .8	71	4.00
.8 to 1.0	39	2.20
1.0 to 1.5	46	2.59
1.5 to 2.0	28	1.58
2.0 to 2.5	8	.45
2.5 to 3.0	2	.11
3.0 to 4.0	2	.11
4.0 to 5.0	2	.11
5.0 to 7.0	2	.11
	1,773	100.00

Thus, of the 1,773 samples taken at station 2, 1,334 (75.3 per cent) contained less than 0.2 parts SO_2 per million parts air; 1,464 (82.6 per cent) contained less than 0.4 part SO_2 per million parts air, and 94.9 per cent contained less than 1 part SO_2 per million parts air. The total number of samples that contained more than 2 parts SO_2 per million parts air was 16, or 0.9 per cent.

Summary of determinations made during definite periods of time.

Month or time.[a]	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
1913.		*Per cent.*		
September [b]	99	5.6	0.87	3.0
October	422	23.9	.42	7.1
November	286	16.1	< .20	1.1
1914.				
March	206	11.6	< .20	.2
April	537	30.2	< .20	1.0
May	223	12.6	.27	3.2
	1,773	100.0	.....	.....
4 to 8 a. m.	34	1.9	< .20	.6
8 a. m. to 12 m.	775	43.7	.22	7.1
12 m. to 6 p. m.	964	54.4	.27	5.5
	1,773	100.0	.....	.....

[a] Determinations were made as follows: September, 1913, A. E. Wells and G. N. Libby; October and November, 1913, H. L. Long; March, April, and May, 1914, H. H. Bartells.

[b] During September the tests at this station were made only at the times when the smoke was blown toward the station. Thus, the average of the September tests was naturally higher than that of the following months, which include determinations made under all conditions.

Summary of determinations made under certain wind and smoke conditions.

Condition of wind.[a]	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Smoke drifting along path in angle COD or path OED	217	12.3	1.00	7.1
Smoke blown by high or moderate wind along path COD	144	8.1	.50	1.15
Smoke blown along straits or on Contra Costa Bluffs	761	43.0	< .20	.95
South or southwest wind; smoke along path in angle EOF	201	11.3	< .20	.4
Southeast or east wind	316	17.8	< .20	.25
Northeast or north wind	134	7.5	< .20	< .20
	1,773	100.0	.....	.....

[a] For "paths" referred to, see Plate VI.

DETAILED RESULTS.

The details of determinations are presented in the tabulation following.

Detailed results of determinations at station 2.

DETERMINATIONS MADE WHEN THERE WAS A VERY LIGHT WEST WIND; THE SMOKE BEING GENTLY BLOWN OR DRIFTED ALONG A PATH IN THE ANGLE COD,[a] OR ALONG THE PATH OED.[a]

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1913.				*Tons.*
Sept. 18	19	0.75	2.1	32	Oct. 27	11	1.10	1.6	40
22	21	1.05	2.0	26	28	10	2.40	7.1	40
26	39	1.15	3.0	17	Nov. 3	2	.50	1.0	19
Oct. 9	14	.60	1.0	11	22	6	.60	.9	36
10	7	1.10	1.4	21	1914.				
11	5	.55	.6	17	May 8	4	.70	1.0	36
14	28	.50	1.0	16	10	6	.90	1.0	38
16	10	.20	.4	2	11	7	1.70	3.0	45
17	6	.80	1.1	18	12	9	1.30	3.2	36
20	6	1.55	2.15	8					
21	5	2.40	4.3	16					
22	2	1.60	1.9	12		217	1.00	.....	.....

DETERMINATIONS MADE WHEN THERE WAS A MODERATE OR BRISK WEST WIND; THE SMOKE BEING BLOWN ALONG A PATH IN THE ANGLE COD,[a] OR ALONG THE PATH OED.[a]

1913.				*Tons.*	1914.				*Tons.*
Sept. 20	12	0.25	0.45	32	Apr. 2	5	0.70	1.00	23
Oct. 8	21	.70	1.10	11	25	1	.80	.80	29
10	5	.60	.80	21	26	5	.40	.60	27
13	18	.30	.70	14	May 1	2	.40	.40	27
15	16	.30	.50	14	6	2	.40	.60	41
23	10	.65	.95	12	8	4	.45	.60	36
24	4	.60	.75	13	10	2	.60	.80	38
29	17	.50	.95	38	12	5	.50	.60	36
30	2	.45	.60	16					
Nov. 10	1	1.10	1.10	33		144	.50	.....	.....
19	6	.30	.70	16					
21	6	.80	1.80	35					

DETERMINATIONS MADE WHEN THE WIND WAS DIRECT FROM THE WEST, AND THE SELBY SMOKE WAS BEING BLOWN ALONG STRAITS, SOUTH OF STATION.

1913.				*Tons.*	1914.				*Tons.*
Oct. 9	8	0.50	0.80	11	Apr. 10	17	<0.20	<0.20	27
10	12	.20	.40	21	13	10	<.20	<.20	27
17	9	.20	.30	18	14	20	<.20	<.20	20
20	6	.25	.30	8	15	20	<.20	<.20	16
21	14	.20	.55	16	16	12	<.20	<.20	17
27	7	.45	.65	40	17	4	<.20	<.20	21
28	14	.45	.95	40	20	6	<.20	<.20	27
29	4	.35	.35	38	22	20	<.20	<.20	21
30	3	.30	.30	18	23	19	<.20	<.20	33
Nov. 6	3	<.20	<.20	11	24	20	<.20	<.20	28
10	6	.20	.40	33	25	19	<.20	<.20	29
19	4	<.20	<.20	16	26	13	<.20	<.20	27
21	7	.30	.50	35	27	20	<.20	<.20	25
22	2	<.20	.20	36	28	20	<.20	<.20	21
					May 4	16	<.20	<.20	28
1914.					6	17	<.20	<.20	41
Mar. 18	10	<.20	<.20	26	8	12	<.20	<.20	35
20	11	<.20	<.20	24	9	18	<.20	<.80	25
21	10	<.20	<.20	31	10	11	<.20	<.20	38
23	5	<.20	<.20	19	11	14	<.20	<.20	45
24	7	<.20	<.20	18	12	6	<.20	<.20	36
26	12	<.20	<.20	22	13	18	<.20	<.20	22
27	20	<.20	<.20	28					
Apr. 7	19	<.20	<.20	27		437	.20	.....	.....
8	12	<.20	<.20	32					

[a] See Plate VI.

Detailed results of determinations at station 2—Continued.

DETERMINATIONS MADE WHEN THE WIND WAS NORTH OF WEST AND THE SELBY SMOKE WAS BLOWN ALONG THE BLUFFS ON THE OPPOSITE SHORE OF THE STRAITS.[a]

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1914.				*Tons.*
Oct. 22	14	<0.20	0.4	.....	Apr. 11	20	<0.20	<0.2	.....
23	9	< .20	< .2	.....	12	20	< .20	< .2	.....
24	13	< .20	< .2	.....	13	10	< .20	< .2	.....
25	5	< .20	< .2	.....	16	8	< .20	< .2	.....
Nov. 6	7	< .20	< .2	.....	May 1	17	< .20	< .2	.....
19	6	< .20	< .2	.....	2	16	< .20	< .2	.....
20	16	< .20	< .2	.....	5	20	< .20	< .2	.....
21	4	< .20	< .2	.....	7	18	.20	< .2	.....
22	5	< .20	< .2	.....					
28	6	< .20	< .2	.....		224	.....	.....	.....
29	10	< .20	< .2	.....					

[a] Total determinations made when the wind was blowing the smoke along a path included in the angle AOC (Pl. VI) include determinations made when the smoke was blown along the straits or along the Contra Costa shore, and equal 761.

DETERMINATIONS MADE WHEN THE WIND WAS FROM THE SOUTH OR SOUTHEAST AND THE SELBY SMOKE WAS BLOWN ALONG A PATH IN THE ANGLE EOF.[a]

1913.				*Tons.*	1914.				*Tons.*
Oct. 9	2	0.20	0.20	.....	Mar. 29	9	<0.20	<0.20	.....
15	8	< .20	.30	.....	30	13	< .20	< .20	.....
16	8	.20	.40	.....	Apr. 2	4	< .20	< .20	.....
17	1	.20	.20	.....	3	13	< .20	< .20	.....
29	2	< .20	.20	.....	6	18	< .20	< .20	.....
Nov. 10	4	< .20	.20	.....	9	9	< .20	< .20	.....
					10	3	< .20	< .20	.....
1914.					17	8	< .20	< .20	.....
Mar. 24	10	< .20	< .20	.....	20	11	< .20	< .20	.....
25	20	< .20	< .20	.....	21	20	< .20	< .20	.....
26	8	< .20	< .20	.....					
28	20	< .20	< .20	.....		201	.20	.....	.....

[a] See Plate VI.

DETERMINATIONS MADE WHEN THE WIND WAS FROM THE EAST OR SOUTHEAST.

1913.					1913.				
Sept. 18	5	<0.20	0.25	.....	Nov. 25	5	<0.20	<0.20	.....
20	3	< .20	.20	.....	26	12	< .20	< .20	.....
30	8	< .20	< .20	.....					
Oct. 31	14	< .20	< .20	.....	1914.				
Nov. 3	14	< .20	< .20	.....	Mar. 19	10	< .20	< .20	.....
4	16	< .20	< .20	.....	29	10	< .20	< .20	.....
5	21	< .20	< .20	.....	30	7	< .20	< .20	.....
6	7	< .20	< .20	.....	31	19	< .20	< .20	.....
7	17	< .20	< .20	.....	Apr. 1	20	< .20	< .20	.....
10	4	< .20	< .20	.....	2	12	< .20	< .20	.....
11	18	< .20	< .20	.....	4	15	< .20	< .20	.....
12	10	< .20	< .20	.....	8	8	< .20	< .20	.....
14	13	< .20	< .20	.....	17	8	< .20	< .20	.....
17	14	< .20	< .20	.....	18	17	< .20	< .20	.....
19	1	< .20	< .20	.....					
24	8	< .20	< .20	.....		316	< .20	.....	.....

DETERMINATIONS MADE WHEN THE WIND WAS FROM THE NORTH OR NORTHEAST.

1913.					1914.				
Sept. 11	19	<0.20	<0.20	.....	Mar. 23	5	<0.20	<0.20	.....
Oct. 15	2	< .20	< .20	.....	Apr. 29	20	< .20	< .20	.....
17	5	< .20	< .20	.....	30	20	< .20	< .20	.....
18	16	< .20	< .20	.....					
19	16	< .20	< .20	.....		134	< .20	.....	.....
20	6	< .20	< .20	.....					
Nov. 8	16	< .20	< .20	.....					
13	5	< .20	< .20	.....					
15	4	< .20	< .20	.....					

At times it was difficult to tell the exact conditions under which the tests were made, especially after the bag house was operating and the smoke was cleared from solids. Frequently the wind apparently was blowing the smoke in a direct line from the smokestack to the station, yet at the station only a slight trace, sometimes none, of sulphur dioxide was found. At other times the smoke apparently was blown along the straits to the south of the station, yet an appreciable quantity of sulphur dioxide was determined at the station.

DISCUSSION OF DETERMINATIONS MADE AT STATION 2, WHEN SMOKE WAS BEING BLOWN BY A VERY LIGHT WEST WIND OR DRIFTING ALONG A PATH INCLUDED IN THE ANGLE COD OR FOLLOWING THE LINE OED ALONG THE BLUFFS ON NORTH SIDE OF STRAITS.[a]

Ninety-two of the 217 samples taken under these conditions were taken when the smoke was observed in the immediate vicinity. The data of these 92 tests are given below. Also, are given the data of the 8 samples taken when the sulphur dioxide was detected by smell.

Determinations made at times when the Selby smoke was observed by vision or by smell in the immediate vicinity.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1914.				*Tons.*
Sept. 18	6	1.15	2.1	32	Apr. 2	5	0.70	1.0	24
22	11	1.40	1.8	26	May 8	4	.80	1.0	36
26	18	1.75	3.0	17	10	6	.90	1.0	38
Oct. 8	2	1.40	1.45	11	11	7	1.70	3.0	45
17	2	.85	1.1	18	12	9	1.30	3.2	36
20	6	1.55	2.15	8					
21	3	3.30	4.3	16		92	1.50	7.1	.....
28	4	4.15	7.1	40					
29	1	1.55	1.55	38					
Nov. 3	2	1.00	1.1	19					
22	6	.60	.9	36					

Determinations made when the Selby smoke was smelled at station 2.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.	Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.				Average.	Maximum.	
1913.				*Tons.*	1914.				*Tons.*
Sept. 26	1	3.00	3.0	17	May 12	1	3.20	3.2	36
Oct. 21	3	3.40	4.3	16					
28	3	5.70	7.1	40		8	.....	.....	.....

[a] See Plate VI.

The data obtained on certain days when the maximum contamination of the atmosphere in the vicinity of the station was found, and the most unfavorable wind conditions existed, are given below for further study.

SEPTEMBER 18, 1913.

Smelter data.

Number of sintering machines in operation, 3.
Rate of sulphur elimination, 32 tons per 24 hours.
Wind record at smelter, southwest wind; velocity one-half mile per hour.

Station 2 data.

The results of tests made by A. E. Wells and G. N. Libby were as follows:

Results of sampling at station 2, September 18, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.[a]
p. m.		
2.10	0.4	Selby smoke drifting on line OED.[b]
2.20	.6	Selby smoke drifting on line OED; slight oil smell at station.
2.30	.6	Slight oil smell at station.
2.40	.4	No smell.
3.00	.4	Slight oil smell.
3.10	.3	Do.
3.40	1.0	Selby smoke drifting on line OED: hazy; slight oil smell.
4.00	.4	Selby smoke drifting on line OE; less hazy; slight oil smell.
4.10	.3	Slight haze; slight oil smell.
4.15	.6	Selby smoke drifting on line OED up to Glen Cove.
4.22	2.1	Selby smoke visible around station.
4.30	1.7	Do.
4.35	1.4	Selby smoke clearing around station.
4.40	.9	Clearer around station.
4.50	.8	Wind slightly stronger.
5.00	.9	Wind strong.
5.10	.7	
5.20	.5	
5.35	.3	
	.75	

[a] At no time did the smoke appear to rise over the bluffs north of the straits, or to go north of Glen Cove resort. The line of drift was essentially along OED (Pl. VI).
[b] See Plate VI.

SEPTEMBER 26, 1913.

Smelter data.

Number of sintering machines in operation, 2.
Rate of sulphur elimination, 17 tons per 24 hours.
Wind record at smelter, 7 a. m. to 3 p. m., west; velocity 3 miles per hour.

Station 2 data.

The results of tests at station 2 made by A. E. Wells and G. M. Libby were as follows:

Results of sampling at station 2, September 26, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.[a]
a. m.		
8.10	0.8	Slight smell of oil vapors.
8.20	.4	Do.
8.30	1.0	Distinct smell of oil vapors.
8.40	1.5	Strong and nauseating smell of oil fumes.
8.50	1.2	Do.
8.55	.6	Slight smell oil vapors.
9.15	1.0	No smell of oil vapors.
9.30	.5	Slight westerly breeze.
9.45	.6	Do.
10.00	1.5	Hazy around station; smoke.
10.15	1.9	Do.
10.30	1.6	Do.
10.45	1.7	Hazy around station; oil smell.
10.55	1.2	Do.
11.10	1.6	Do.
11.25	2.5	Smoke puffs passing station; no smell.
11.35	1.3	Hazy, but no puffs.
11.55	.5	Smoke on channel south of station.
p. m.		
12.20	1.2	Smoke again headed to station.
12.30	1.9	Slight westerly wind; smoky in Glen Cove.
12.45	2.9	Smoke puffs passing station; slight smell of SO_2.
12.55	2.4	Smoke puffs passing station; no smell of SO_2.
1.10	.9	Slight west wind clearing around station.
1.20	.7	Do.
1.35	.5	Clear.
1.50	1.0	Smoke drifting in; slight haze in Glen Cove.
2.05	.9	Haze.
2.15	1.2	Do.
2.25	1.7	Smoke drifting around station; slight oil smell.
2.35	2.0	Smoke drifting around station; strong oil smell.
2.45	2.0	Do.
3.00	1.3	Smoke drifting around station; slight oil smell.
3.15	1.8	Smoke drifting around station; no smell.
3.30	1.3	Wind freshening, clearing air; no smell.
3.45	.4	Wind stronger; clear at station.
4.10	< .2	Wind blowing smoke along straits.
4.40	< .2	
4.55	< .2	
5.15	< .2	

[a] Smoke was drifting in angle COD (Pl. VI) toward the station all day; hence the dissipation of SO_2 by dispersion was reduced to a minimum. These data, consequently, represent the worst conditions.

October 21, 1913.

Smelter data.

Number of sintering machines in operation, 2.

Rate of sulphur elimination, 16 tons per 24 hours.

Wind record at smelter, west or southwest: velocity 3 miles per hour.

Station 2 data.

The results of tests made at station 2 by H. L. Long were as follows:

Results of sampling at station 2, October 21, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.[a]
p. m.		
1.35	0.3	Smoke drifting along straits south of station.
1.40	.1	Do.
1.50	4.3	Smoke puffs drifting past station; smell SO_2.
2.00	.4	Smoke back along straits.
2.25	2.3	Smoke puffs drifting past station; smell SO_2.
2.40	1.3	Smoke shifting back to straits.
3.10	.5	Smoke drifting up channel.
3.30	.3	Do.
3.45	.9	Smoke coming toward station.
3.55	3.6	Smoke drifting past station.
4.00	.2	Smoke over straits.

OCTOBER 28, 1913.

Smelter data.

Number of sintering machines in operation, 2.
Rate of sulphur elimination, 40 tons per 24 hours.
Wind record at smelter, west wind; velocity 7 miles per hour.

Station 2 data.

The results of tests made by H. L. Long at station 2 were as follows:

Results of sampling at station 2, October 28, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
9-10.45	[a] 0.3	Smoke along straits.
11.15	7.1	Smoke drifting to station; smell SO_2.
11.30	4.8	
11.45	1.9	Smoke drifting to station and along straits.
p. m.		
12.05	1.0	
12.15	2.1	
12.35	5.5	Smoke drifting to station; smell SO_2.
12.45	1.2	Smoke drifting to station and along straits.
1.15	.8	
1.40	.4	
2.15	1.9	
2.45	.9	Smoke drifting along straits.
3.15	.9	

[a] Average.

MAY 11, 1914.

Smelter data.

Number of sintering machines in operation, 3.
Ropp roaster operating.
Rate of sulphur elimination, 45 tons per 24 hours.
Wind record at smelter, southwest; velocity, 4 to 5 miles.

Station 2 data.

Results of sampling at station 2, May 11, 1914.

Time.	Parts of SO_2 per million parts of air.	Notes.
5 a. m. to 12.30 p. m.	[a] <0.2	Smoke along Contra Costa shore.
p. m.		
1.00	1.2	Smoke drifting to station.
1.20	3.0	Smoke drifting to station; no smell.
1.40	1.8	Smoke clearing locally.
2.00	1.6	Smoke along straits.
2.30	1.6	Smoke drifting toward Glen Cove.
3.00	1.8	Smoke along straits, on line OE.[b]
3.15	.4	Smoke along straits; wind brisker.

[a] Average. [b] See Plate VI.

MAY 12, 1914.

Smelter data.

Number of sintering machines in operation, 3.
Ropp roaster in operation.
Rate of sulphur elimination, 38 tons per 24 hours.
Wind record at smelter, southwest; velocity, 4 to 5 miles.

Station 2 data.

Results of sampling at station 2, May 12, 1914.

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
11.00	<0.20	Smoke going southeast along straits.
11.30	.60	Smoke drifting to station.
m.		
12.00	1.20	Smoke around station.
p. m.		
12.20	3.20	Smoke around station; SO_2 smelled.
12.45	1.60	Smoke around station; clearing slightly.
1.10	.80	Smoke clearing at station; strong oil smell.
1.35	1.00	Smoke all over straits and vicinity.
2.00	1.20	Do.
2.30	1.00	Smoke along straits.
3.00	1.00	Do.
3.30	.80	Do.
4.00	.60	Smoke along line OED[a]
4.30	< .20	Smoke going along Contra Costa shore.
5.00	< .20	Do.

[a] See Plate VI.

As a marked contrast to the data of October 28, we have the data of October 29, when the sulphur elimination for the stack was practically the same. On October 28 the smoke was drifting over toward the station, and on October 29 was blown to that point by a moderate or high west wind. Under the conditions of October 29, dispersion as well as diffusion aided in the dissipation of the sulphur dioxide.

OCTOBER 29, 1913.

Smelter data.

Number of sintering machines in operation, 2.
Ropp roasters in operation, 1.
Rate of sulphur elimination, 38 tons per 24 hours.
Smelter wind records, southwest; velocity, 12 miles per hour.

Station 2 data.

Results of sampling at station 2, October 29, 1913.

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
10.25	0.6	Smoke blown direct to station.
10.45	.5	
11.10	.3	
11.35	<.2	
11.50	<.2	
p. m.		
12.20	.2	
12.45	.3	
1.30	.9	
1.45	.8	
2.15	.4	
2.45	.2	
3.10	.6	
3.30	.9	
4.00	.5	
4.35	.2	
4.50	.4	

The approximate periods of time certain concentrations were present in the air at station 2 were as follows:

Approximate periods certain proportions of SO_2 were present in air at station 2.

Parts of SO_2 per million parts of air.	Period.	Proportion of total sampling time.
	Minutes.	*Per cent.*
5.0 to 7.5	35	0.08
>3.0	65	.14
>2.0	180	.40
>1.0	1,220	2.70
>0.5	3,330	7.40

The approximate periods of time that certain concentrations were present in the air at station 2 on different days were as follows:

1. Between 5 and 7.5 parts of SO_2 per million parts of air:

Date.	Length of time (minutes per period).
Oct. 28	25
	10
Total	35

2. More than 3 parts of SO_2 per million parts of air:

Date.	Length of time (minutes per period).
Oct. 20	10
Oct. 21	5
Oct. 28	25
	10
May 12	15
Total	65

3. More than 2 parts of SO_2 per million parts of air:

Date.	Length of time (minutes per period).
Sept. 18	5
Sept. 22	10
	25
	10
Oct. 20	10
Oct. 21	20
	15
Oct. 28	25
	25
May 11	20
May 12	15
Total	180

4. More than 1 part of SO_2 per million parts of air:

Date.	Length of time (minutes per day)
Sept. 18	20
Sept. 22	115
Sept. 26	315
Oct. 8	25
Oct. 10	60
Oct. 17	5
Oct. 20	60
Oct. 21	45
Oct. 22	20
Oct. 27	120
Oct. 28	120
Oct. 29	10
Nov. 10	15
Nov. 19	20
May 11	120
May 12	120

5. More than 0.5 part of SO_2 per million parts of air:

Date.	Length of time (minutes per day).
Sept. 18	95
Sept. 22	235
Sept. 26	420
Oct. 8	195
Oct. 9	120
Oct. 10	140
Oct. 11	60
Oct. 13	30
Oct. 14	200
Oct. 17	20
Oct. 20	70
Oct. 21	60
Oct. 22	20
Oct. 23	180
Oct. 24	60
Oct. 27	250
Oct. 28	240
Oct. 29	75
Oct. 30	10
Nov. 3	30
Nov. 10	15
Nov. 19	15
Nov. 21	25
Nov. 22	50
Apr. 2	60
Apr. 25	10
Apr. 26	15
May 6	15
May 8	90
May 10	200
May 11	130
May 12	200
Total	3,330

DETERMINATIONS MADE IN THE COVES WEST OF STATION 2, COMPRISING GLEN, ELLIOTT, AND DOS REIS COVES.

GENERAL SUMMARY.

Total number of samples taken, 95.

Average sulphur dioxide content of samples, 0.20 part of SO_2 per million parts of air.

Maximum sulphur dioxide content of samples, 2.25 parts of SO_2 per million parts of air.

Range of results—

Range of results of determinations made in the coves west of station 2.

Limits of concentration (parts SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	68	71.7
.2 to .4	10	10.5
.4 to .6	10	10.5
.6 to .8	2	2.1
.8 to 1.0	1	1.0
1.0 to 1.5	3	3.2
1.5 to 2.0	0	.0
2.0 to 2.5	1	1.0
	95	100.0

Summary of determinations made within certain time limits.[a]

Month or time.	Number.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
September	31	32.6	0.30	1.4
October	31	32.6	<.20	.2
November	.....	.....	.....	.....
March	.....	.....	.....	.....
April	9	9.5	<.20	.25
May	24	25.3	.30	2.25
	95	100.0	.....	.....
4 a. m. to 8 a. m.	7	7.4	.20	.4
8 a. m. to 12 m.	19	20.0	.50	2.25
12 m. to 6 p. m.	69	72.6	<.20	1.4
	95	100.0	.....	.....

[a] Determinations were made as follows: In September, 1913, by A. E. Wells; in October, 1913, by G. N. Libby; in April and May, 1914, by H. L. Long.

Summary of determinations made under certain wind conditions.

Condition of wind.[a]	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
Slight west wind; smoke in path COD	4	4.2	1.30	2.25
Moderate or strong west wind; smoke angle, COD	25	26.3	.25	1.40
Smoke along straits in path AOC	.....	.....	.....	.....
South or southeast wind; smoke in path EOF	38	40.0	<.20	.5
East or southeast wind	.....	.....	.....	.....
North of northeast wind	2	2.1	<.20	.2
Northwest wind	26	27.4	<.20	.2
	95	100.0	.....	.....

[a] For "paths" referred to see Plate VI.

DETAILED RESULTS.

A tabulation showing detailed results is given herewith.

Detailed results of determinations made in vicinity of Glen, Elliott, and Dos Reis Coves.

DETERMINATIONS MADE WHEN THE SMOKE WAS FROM THE WEST AND WAS LIGHT, CAUSING THE SMOKE TO DRIFT ALONG A PATH IN THE ANGLE COD.[a]

Date.	Place.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter for 24 hours.
			Average.	Maximum.	
1914.					Tons
Apr. 10	Glen Cove	4	1.30	2.25	38

[a] See Plate VI.

MODERATE OR BRISK WEST WIND.

1913.					
Sept. 19	Glen Cove	14	0.50	1.40	31
Sept. 24	do	3	.40	.50	22
1914.					
May 3	do	3	<.20	.25	26
May 9	do	5	<.20	.50	25
		25	.26		

WIND FROM THE SOUTH OR SOUTHWEST.

1913.					
Sept. 25	Dos Reis Cove	6	0.40	0.5	26
Oct. 13	do	11	<.20	<.2	14
1914.					
Apr. 30	do	9	<.20	.25	26
May 9	Glen Cove	3	<.20	<.20	25
May 10	do	5	<.20	.50	38
May 11	Dos Reis Cove	4	<.20	.25	45
		38	<.20		

WIND FROM THE EAST OR SOUTHEAST.

No determinations.

WIND FROM THE NORTH OR NORTHEAST.

1913.					
Sept. 23	Glen Cove	2	<0.20	0.20	

WIND FROM THE NORTHWEST.

1913.					
Sept. 26	Glen Cove	4	<0.20	0.20	
Sept. 24	Elliott Cove	2	<.20	.20	
Oct. 30	do	8	<.20	.20	
1914.					
May 5	Dos Reis Cove	12	<.20	<.20	
Total		26			
		95			

DETAILS OF DETERMINATIONS MADE MAY 10, 1914, WHEN MAXIMUM CONCENTRATIONS WERE FOUND.

The results of determinations made May 10, 1914, when the maximum concentrations were obtained, are given below.

Place of sampling, Glen Cove resort.
Number of sintering machines in operation, 3.
Ropp roaster in operation on ore.
Rate of sulphur elimination, 38 tons per 24 hours.
Wind record at smelter, southwest; velocity, 1 mile.

Results of determinations made near Glen, Elliott, and Dos Reis Coves on May 10, 1914.[a]

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
11.30	1.0	Very light breeze.
11.45	1.2	Directly from smelter.
m.		
12.00	2.25	Smoke puffs visible passing over Glen Cove.
p. m.		
12.15	<.25	Stronger breeze clearing air.

[a] Determinations made by H. L. Long.

DETERMINATIONS MADE ALONG THE VALLEJO-BENICIA ROAD, BETWEEN BENICIA CITY LIMITS AND CARQUINEZ CEMETERY.

GENERAL SUMMARY.

Total number of samples, 111.

Average sulphur dioxide content of samples, 0.22 part of SO_2 per million parts of air.

Maximum sulphur dioxide content of samples, 2.60 parts of SO_2 per million parts of air.

Range of results—

Range of results of determinations made along the Vallejo-Benicia Road between Benicia city limits and Carquinez Cemetery.

Limits of concentration (parts of SO_2 per million parts of air.	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	92	82.9
.2 to .4	4	3.6
.4 to .6	6	5.4
.6 to .8	2	1.8
.8 to 1.0	1	.9
1.0 to 1.5	1	.9
1.5 to 2.0	1	.9
2.0 to 2.5	3	2.7
2.5 to 3.0	1	.9
	111	100.0

Summary of determinations made during certain time limits.[a]

Month or time.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
1913.		*Per cent.*		
September	17	15.3	0.80	2.6
October	31	27.9	.20	.9
November	47	42.4	<.20	.6
1914.				
March				
April	6	5.4	<.20	.2
May	10	9.0	<.20	.75
	111	100.0		
4 a. m. to 8 a. m.				
8 a. m. to 12 m.	27	24.3	<.20	.9
12 m. to 6 p. m.	84	75.7	.25	2.6

[a] Determinations were made as follows: In September, October, and November, 1913, by G. N. Libby; in April and May, 1914, by H. L. Long.

Summary of determinations made under certain wind conditions.

Condition of wind.	Number of determinations.	Proportion of total.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
		Per cent.		
Slight west wind; smoke in path COD[a]	79	63.1	0.30	2.6
Moderate or brisk west wind; smoke in path COD[a] or along straits	17	15.3	< .20	.25
South or southwest wind	7	14.4	< .20	.25
East or southeast wind				
North or northeast wind	8	7.2	< .20	< .20
Northwest wind				
	111	100.0		

[a] See Plate VI.

DETAILED RESULTS.

Detailed results of the determinations are tabulated below.

Detailed results of determinations made along the Vallejo-Benicia Road between the Benicia city limits and Carquinez Cemetery.[a]

WIND FROM WEST AND LIGHT, CAUSING THE SELBY SMOKE TO DRIFT ALONG A PATH INCLUDED IN THE ANGLE COD.[b]

Date.	Place.	Number of tests.	Parts of SO_2 per million parts of air.[a]		Rate of sulphur elimination from smelter for 24 hours.
			Average.	Maximum.	
1913.					*Tons.*
Sept. 24	Near Corcoran's ranch	3	<0.20	0.20	22
Sept. 30	At Rose's house	6	2.00	2.60	15
Oct. 8	Near Corcoran's ranch	6	.30	.50	11
Oct. 10	At Brazil's house	14	.20	.90	18
Nov. 3	Midway saloon	17	< .20	.20	19
Nov. 6	At Brazil's house	23	< .20	.20	11
Nov. 9	Near Corcoran's ranch	7	< .20	.60	10
1914.					
May 10	Midway saloon	3	.50	.75	38
		79	.30		

[a] Determinations made by G. N. Libby. [b] See Plate VI.

Detailed results of determinations made along the Vallejo-Benicia Road between the Benicia city limits and the Carquinez Cemetery—Continued.

MODERATE OR BRISK WEST WIND.

Date.	Place.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter for 24 hours.
			Average.	Maximum.	
1913.					*Tons.*
Oct. 3	At Rose's house	11	0.20	0.25	16
1914.					
Apr. 25	Midway saloon	3	.20	.20	29
May 11	do	3	.20	.25	45
		17	.20		

SOUTH OR SOUTHWEST WIND.

1914.					
Apr. 3	Midway saloon	3	<0.20	<0.20	27
May 9	do	2	< .20	.25	25
May 13	do	2	< .20	< .20	22
		7	< .20		

EAST OR SOUTHEAST WIND.

No determinations.

NORTH OR NORTHEAST WIND.

1913.					
Sept. 30	At Rose's house	8	0.20	0.20	

RESULTS OF DETERMINATIONS MADE AT THE ROSE HOUSE, SEPTEMBER 30, 1913.

The data of September 30 at the Rose house, where the maximum concentrations in these limits were obtained, are given below:

SEPTEMBER 30, 1913.

Number of sintering machines in operation, 2.
Rate of sulphur elimination, 15 tons per 24 hours.
Wind record at smelter—
Before 3.00 p. m., southeast wind.
After 3.00 p. m., west wind.
Velocity of wind, 4 miles per hour.

Results of determinations made at Rose's house, Sept. 30, 1913.[a]

Time.	Parts of SO_2 per million parts of air.	Notes.[a]
11.30 a. m. to 3.30 p. m.	<0.20	Wind from northeast until 3.30 p. m.
3.50 p. m.	2.20	Slight southwest wind; strong oil smell.
3.55 p. m.	2.60	Do.
4.00 p. m.	1.30	Slight southwest wind; slight oil smell.
4.05 p. m.	2.10	Do.
4.15 p. m.	2.00	Do.
4.30 p. m.	1.70	Do.
4.40 p. m.	.50	Moderate southwest wind; no smell.

[a] Determinations made by G. N. Libby.

DETERMINATIONS MADE ALONG THE VALLEJO-BENICIA ROAD BETWEEN THE CARQUINEZ CEMETERY AND THE VALLEJO CITY LIMITS.

The details of determinations made along the Vallejo-Benicia Road between the Carquinez Cemetery and the Vallejo city limits are tabulated below.

Details of determinations made along Vallejo-Benicia Road between Carquinez Cemetery and Vallejo city limits.

Date.	Number of tests.	Parts of SO_2 per million parts of air.		Rate of sulphur elimination from smelter per 24 hours.
		Average.	Maximum.	
				Tons.
Nov. 5	25	<0.20	1.00	19
Nov. 17	7	<.20	.20	17
Apr. 30	10	<.20	.20	26
	42			

During September, October, and November, 1913, the smoke drifted along the path COD or OEF (Pl. VI) more often than in the spring months. During the spring months the wind was from the west and the smoke was carried along the straits to the south of Dillon Point much more often than during the fall. Thus, during the fall months the sulphur dioxide concentration in the air of the agricultural district was greater than in the spring months.

COMPARISON OF DETERMINATIONS MADE SIMULTANEOUSLY IN DIFFERENT PARTS OF THE "SMOKE ZONE."

For the purpose of comparing the sulphur dioxide content of the atmosphere in different parts of the "smoke zone" at a time when the wind was from the west, Table 9 following has been prepared. In this table is given the sulphur elimination from the smelter as determined by calculation and by actual analysis and measurement of the gases leaving the stack.

In most cases where samples were taken simultaneously at two or more points in the path of the smoke stream, a decrease in the sulphur dioxide content of the samples was noted at the point of greatest distance from the smelter. However, due to the great variations caused by local wind currents, it is impossible to determine a ratio of decrease in concentration of sulphur dioxide which could be used as a factor for calculating concentrations at various points.

It should be noted that, during the spring months when the smoke was being blown by a fairly light or moderate west wind directly along the straits in path AOC (Pl. VI), the air at station 2, which was slightly out of the path of the smoke stream, was practically free from sulphur dioxide, while at station 1, in the direct path of the smoke stream, the air contained determinable quantities.

Table 9 follows.

TABLE 9.—*Results of SO_2 determinations made simultaneously*

Date.	Time.	Quantity of sulphur from stack per 24 hours.		General data regarding wind—							
				At smelter.		At station 2.		At station 1.		At automobile laboratory station.	
		Calculated from daily metallurgical reports.	Calculated from analytical data obtained at stack.	Direction.	Velocity, miles per hour.	Direction.	Degree.	Direction.	Degree.	Direction.	Degree.
1913.		*Tons.*	*Tons.*								
Oct. 8	11.45-1.30	11	.....	SW...	12	W....	Moderate	.....	.....	S. of W	Moderate
9	8.30-1.30	11	.....	Calm..	.....	.....	.....	.....	.....	W....	Slight...
				W....	4	W....	Slight.				
10	11.30-4.30	21	.....	Calm..	.....	.....	.....	.....	.....	SW...	...do....
				SW...	5	W....	Slight.				
14	8.30-4.30	16	18	W....	4	W....	...do....	W....	.....	W....	...do....
				SW...	6	.....	.....	SW...	Slight.		
				SW...	6						
15	10.00-1.00	14	12	SW...	4	SW and W.	Slight...	W....	...do..	W....	...do....
16	9.00-3.00	2	2	Calm..	.....	.....	.....	.....	.....	W....	...do....
				SW...	6	W....	Slight...	W....	Slight.		
17	7.30-4.30	18	12	Calm..	.....	W....	...do....	W....	...do..	W....	...do....
				SW...	½						
				Calm.							
20	2.30-5.00	8	.....	Calm..	.....	W....	...do....	W....	...do..	W....	...do....
				SW...	2						
				Calm.							
21	11.00-4.00	16	16	W....	2	W....	...do....	W....	...do..	W....	Brisk...
				SW...	4						
22	8.00-4.00	12	11	Calm..	.....	W....	...do....	W....	...do..	W....	Slight...
				Calm and SW.							
23	12.00-3.00	12	.....	W....	5	W....	...do....	W....	...do..	W....	...do....
25	11.00-2.00	9	10	SW...	3	.....	.....	W....	...do..	W....	...do....
				Calm.							
27	9.00-1.00	40	36	Calm..	.....	Slight.	.....	.....	.....	.....	.....
				Calm..	.....	N. of W	Slight...	N. of W.	Slight.	N. of W	Slight.
				Calm..							
	1.00-4.00	40	39	Calm..	.....	.....	.....	.....	.....	.....	.....
				Calm..	.....	W....	Slight...	W....	Slight.	W....	Slight.
28	9.00-11.00	40	36	Calm..	.....	Slight.	.....	.....	.....	W....	...do....
				W....	6	N. of W	Slight...	W....	Slight.		
	11.00-3.00	40	41	W....	6	W....	...do....	W....	...do..	W....	...do....
29	9.00-3.30	37	36	SW...	8	.....	.....	.....	.....	W....	Strong..
					25	S.....	Strong..	W....	Strong.		
					30						
30	1.40-2.40	16	18	SW...	15	W....	...do....	W....	...do..	N.....	...do....
Nov. 3	2.00-3.30	38	38	SW...	9	W....	Slight...	W....	Slight.	W....	Slight...
											Calm.
4	8.00-4.00	17	15	Calm..	.....	.....	.....	.....	.....	Calm..	.....
				SW...	5	Calm..	.....	Calm.			
10	10.45-4.00	33	35	SW...	9	W....	Moderate	W....	Moderate.	.....	.....
					6						
19	12.30-1.00	16	.....	SW...	7	W....	...do....	W....	...do..	W....	Moderate
21	10.00-2.00	35	36	Calm..	.....	W....	Slight...	W....	Slight.	W....	Slight...
22	11.00-2.30	36	31	W....	5	W....	...do....	W....	...do..	W....	...do....
1914.											
Mar. 21	12.00-4.00	31	.....	W....	14	W....	Strong..	W....	Strong.	.....	.....
23	10.00-1.00	18	.....	SW...	6	W....	...do....	W....	...do..	.....	.....
25	12.00-5.00	21	.....	W....	9	SW...	...do....	W....	...do..	.....	.....
26	9.30-5.00	22	.....	W....	12	NW...	...do....	.....	.....	.....	.....
				SW...	10	SW...	...do....	W....	Strong.		
27	8.00-5.00	28	.....	W....	10	SW...	...do....	.....	.....	.....	.....
					12	NW...	...do....	W....	Strong.		

* See Plates VI and VII.

in different parts of "smoke zone." [a]

General notes regarding smoke.	Data regarding SO_2.								
	Station 2.			Station 1.			Automobile laboratory station.		
	Number of tests.	Parts of SO_2 per one million parts of air.		Number of tests.	Parts of SO_2 per one million parts of air.		Place.	Number of tests.	Parts of SO_2 per one million parts of air.	
		Average.	Maximum.		Average.	Maximum.			Average.	Maximum.
Blowing toward station 2	5	0.90	1.15	.....	.....	.....	Corcoran's ranch..	5	0.35	0.50
.....do.....	15	.60	1.00	.....	.....	.....	Anderson Hotel...	12	<.20	<.20
Drifting up channel of straits; angle AOC.	15	.40	.80	5	1.00	2.40	Shipyard.....	9	<.20	<.20
Blown along straits and to station.	28	.50	1.00	20	<.20	.20	Road to Passalacqua's house.	22	.40	1.00
Blown along straits to Benicia.	11	.30	.50	8	.20	.80	East of schoolhouse.	9	.20	.40
Drifting to White's and along straits.	18	<.20	.40	19	<.20	.20	Passalacqua's house.	18	<.20	<.20
Drifting around smelter and up straits.	16	<.20	1.00	21	<.20	.40	Prince's, K Street.	22	<.20	.40
Drifting past north tower into Benicia.	9	1.10	2.20	8	.60	1.60	City wharf.....	12	<.20	.20
Blown along straits or thick around north tower.	12	1.10	4.30	12	<.20	.30	Cemetery north of Benicia.	10	<.20	.20
Blown along straits and Contra Costa shore.	16	.25	1.90	24	<.20	.20	Eben Selby's house.	17	.30	.50
Drifting along straits and to station 2.	5	.80	.90	7	<.20	.20	Arsenal.....	10	<.20	.20
Drifting up straits; oil smell at Benicia.	.....	.....	.....	9	<.20	.20	Shipyard.....	10	.30	.80
Heavy along straits close to Contra Costa shore.	7	.50	.60	10	.30	.40	Dana Place.....	10	<.20	<.20
Drifting up straits close to north tower; path AOC.	11	1.10	1.60	12	.80	1.90	.....do.....	9	.70	1.10
Heavy along straits close to Contra Costa shore.	7	.40	.80	6	.20	.20	Catholic cemetery.	6	<.20	.40
Heavy along straits close to north tower; path AOC.	11	1.40	7.10	14	.50	1.50	.....do.....	15	<.20	.20
Scattered over straits and toward north tower.	16	.40	.90	16	<.20	.30	Carty's place.....	17	<.20	.40
Coming up straits.....	2	.40	.60	5	.40	.80	Elliott Cove.....	4	<.20	<.20
Drifting along straits; path COD.	4	.75	1.00	4	<.20	.20	Midway saloon....	5	<.20	<.20
Hovering at smelter.....	16	<.20	.20	26	<.20	.20	Near road to Fisher's.	13	<.20	<.20
Drifting up straits; path AOC.	14	.20	1.10	14	.45	.90	Anderson Hotel...	2	.20	.20
Going up straits; path AOC.	2	.25	.30	2	.30	.40	.....do.....	2	.20	.20
Up straits and to north tower.	12	.55	1.80	13	.20	.50	.....do.....	10	<.20	.40
Drifting up straits and to north tower.	6	.60	.90	8	.25	.50	Tannery.....	9	.20	.70
Blown along straits; path AOC.	5	<.20	<.20	9	<.20	<.20	.....	.....	.....	.....
Path AOC.....	4	<.20	<.20	5	.20	.60	.....	.....	.....	.....
.....do.....	11	<.20	<.20	14	.30	1.00	.....	.....	.....	.....
.....do.....	17	<.20	<.20	19	.20	.35	.....	.....	.....	.....
.....do.....	20	<.20	<.20	23	.20	.35	.....	.....	.....	.....

TABLE 9.—*Results of SO_2 determinations made simultaneously*

Date.	Time.	Quantity of sulphur from stack per 24 hours.		General data regarding wind—							
				At smelter.		At station 2.		At station 1.		At automobile laboratory station.	
		Calculated from daily metallurgical reports.	Calculated from analytical data obtained at stack.	Direction.	Velocity, miles per hour.	Direction.	Degree.	Direction.	Degree.	Direction.	Degree.
1914.		*Tons.*	*Tons.*								
Apr. 3	2.00-5.00	27	.....	W....	2	.....	.....	.....	.....	.....	.....
				SW...	4	SW...	Slight...	W.....	Slight.	W....	Slight.
6	10.00-2.00	28	.....	W....	7	.....	.....	.....	.....	.....	.....
				SW...	8	W....	Slight...	W.....	Slight.	.....	.....
7	8.00-2.00	27	.....	W....	5	.....	.....	.....	.....	.....	.....
					4	W....	Slight...	W.....	Slight.	.....	.....
8	8.00-1.00	33	.....	SW...	5	.....	.....	.....	.....	.....	.....
					7	SW...	Slight...	W.....	Slight.	W....	Slight...
10	10.00-4.00	27	.....	W....	7	.....	.....	.....	.....	.....	.....
					14	W....	Strong..	W.....	Strong.	.....	.....
11	9.00-11.00	28	.....	W....	7	.....	.....	.....	.....	.....	.....
				SW...	5	W....	Slight...	W.....	Slight.	.....	.....
13	8.00-2.30	27	.....	W....	7	.....	.....	.....	.....	.....	.....
					5	W....	Moderate	W.....	Moderate.	.....	.....
14	8.00-2.00	20	.....	SW...	8	.....	.....	.....	.....	.....	.....
					6	W....	Moderate	W.....	Slight.	.....	.....
15	2.00-5.00	16	.....	SW...	12	W....	Strong...	W.....	Strong.	.....	.....
16	2.00-5.00	17	.....	SW...	5	.....	.....	.....	.....	.....	.....
				W....	6	W....	Strong..	W.....	Strong.	W....	Strong..
20	3.00-4.30	27	.....	W....	10	.....	.....	.....	.....	.....	.....
				SW...	8	W....	Strong..	W.....	Strong.	.....	.....
22	8.00-5.00	21	.....	SW...	12	.....	.....	.....	.....	.....	.....
					11	W....	Strong..	W.....	Strong.	.....	.....
23	8.00-4.30	33	.....	SW...	8	.....	.....	.....	.....	.....	.....
					12	W....	Strong..	SW....	Strong.	.....	.....
24	8.00-3.00	28	.....	SW...	6	.....	.....	.....	.....	.....	.....
					8	W....	Strong..	W.....	Strong.	.....	.....
25	8.00-4.00	29	.....	W....	8	.....	.....	.....	.....	.....	.....
				SW...	11	W....	Strong..	W.....	Strong.	W....	Strong..
26	10.00-5.00	27	.....	W....	9	.....	.....	.....	.....	.....	.....
					8	W....	Strong..	W.....	Strong.	.....	.....
27	8.00-3.30	25	.....	SW...	7	W....	...do....	W.....	Moderate.	.....	.....
					8	.....	.....	.....	.....	.....	.....
28	10.00-2.30	21	.....	SW...	6	.....	.....	.....	.....	W....	Strong..
					7	W....	Strong..	W.....	Strong.	SW...	....do...
May 1	8.00-10.00	27	.....	W....	8	W....	Slight...	W.....	Slight.	.....	.....
2	2.00-3.00	24	.....	SW...	12	.....	.....	.....	.....	.....	.....
					1	NW...	Strong..	W.....	Strong.	W....	Strong..
3	9.00-3.00	26	.....	SW...	9	.....	.....	.....	.....	.....	.....
					10	W....	Strong..	W.....	Strong.	W....	Strong..
4	8.00-1.00	28	.....	SW...	9	.....	.....	.....	.....	.....	.....
					11	W....	Strong..	SW....	Strong.	S. of W.	Strong..
5	10.00-5.00	29	.....	SW...	7	.....	.....	.....	.....	.....	.....
					11	W....	Strong..	W.....	Strong.	.....	.....
6	8.00-2.00	41	.....	S.....	4	.....	.....	.....	.....	.....	.....
					8	W....	Strong..	SW. to NW.	.....	.....	.....
7	10.00-5.00	40	.....	SW...	7	.....	.....	.....	.....	.....	.....
					8	W....	Moderate	W.....	Moderate.	.....	.....
8	8.00-5.00	36	.....	SW...	4	.....	.....	WSW..	.....	.....	.....
					5	W....	Slight...	NW.			
9	5.00-9.00	25	.....	SW...	4	.....	.....	.....	.....	.....	.....
					5	W....	Strong..	W.....	Strong.	W....	Strong..
10	7.00-10.30	38	.....	SW...	3	.....	.....	.....	.....	.....	.....
					4	W....	Slight...	W.....	Slight.	W....	Strong..
	11.30-12.30	38	.....	SW...	.....	W....	...do....	SW....	...do..	SW...	Slight...
11	12.30-3.00	45	.....	SW...	4	.....	.....	W.....	.....	.....	.....
					5	W....	Slight...	NW....	Slight.	SW...	Slight.
12	10.00-2.00	36	.....	SW...	5	.....	.....	W.....	...do..	W....	...do....
					4	W....	Slight.				

in different parts of "smoke zone"—Continued.

General notes regarding smoke.	Data regarding SO_2.								
	Station 2.			Station 1.			Automobile laboratory station.			
	Number of tests.	Parts of SO_2 per one million parts of air.		Number of tests.	Parts of SO_2 per one million parts of air.		Place.	Number of tests.	Parts of SO_2 per one million parts of air.	
		Average.	Maximum.		Average.	Maximum.			Average.	Maximum.
Smoke along channel; path AOC.	.....	.....	.....	9	.20	.40	Carty's place.....	9	<.20	.20
Path AOC.....	9	.20	.20	12	.20	.40	.....	.....	.....	.....
Path AOC	12	<.20	<.20	16	.50	.80	.....	.....	.....	.....
Path AOC	10	<.20	<.20	12	<.20	.40	Shipyard.....	8	.30	.60
Path AOC	14	<.20	<.20	13	.25	.60	.....	.....	.....	.....
Path AOC	5	<.20	<.20	6	<.20	.20	.....	.....	.....	.....
Path AOC	13	<.20	<.20	15	.20	.40	.....	.....	.....	.....
Path AOC	13	<.20	<.20	16	.40	.80	.....	.....	.....	.....
.....do.....	8	<.20	<.20	8	.35	.80	.....	.....	.....	.....
Path AOC	8	<.20	<.20	9	.30	.80	Anderson Hotel...	6	<.20	.20
Path AOC	4	.20	<.20	5	.30	.40	.....	.....	.....	.....
Path AOC	20	<.20	<.20	22	.35	1.00	.....	.....	.....	.....
Path AOC	19	<.20	<.20	22	.30	.60	.....	.....	.....	.....
Path AOC	20	<.20	<.20	18	.40	.60	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	Shipyard and Carty's.	17	.25	.60
Path AOC	20	<.20	.80	19	.30	.60	Anderson Hotel...	6	.20	.20
.....	.....	.....	.....	.....	.....	.....	Midway saloon....	5	.20	.40
Path AOC	18	.20	.60	19	.45	.60	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Path AOC	20	<.20	.20	23	.50	.80	.....	.....	.....	.....
.....do.....	10	<.20	.60	12	.50	.80	Shipyard.....	10	.40	.80
.....	.....	.....	.....	.....	.....	.....	Arsenal.....	7	<.20	.20
Path AOC	4	.25	.40	6	.35	.60	.....	.....	.....	.....
Path AOC	4	<.20	<.20	3	.30	.40	Anderson Hotel...	6	.20	.40
.....	12	<.20	.20	18	.60	1.00	At shipyard and Carty's place.	20	.20	.60
Path AOC.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Path AOC	7	<.20	<.20	12	<.20	.20	At shipyard and Carty's place.	17	<.20	.40
Path AOC	16	<.20	<.20	18	.50	.80	.....	.....	.....	.....
Along path AOC.....	13	<.20	.60	15	.50	.80	.....	.....	.....	.....
Along path AOC.....	11	<.20	<.20	22	.50	.70	.....	.....	.....	.....
Along path COD	19	.30	1.00	23	.30	.55	.....	.....	.....	.....
In path COD.....	8	.20	.80	9	.35	.60	Shipyard.....	7	.45	.75
In path COD.....	5	.45	1.00	12	.40	.60	Carty's place.....	12	.35	.75
.....do.....	4	.90	1.00	4	.30	.40	Glen Cove.....	4	1.30	2.25
.....do.....	1	1.00	3.00	8	.30	.60	City wharf.....	4	<.20	.40
Path COD	6	1.50	3.20	.....	.....	.....	Carty's place.....	7	.90	1.25

In order to make clearer the data obtained simultaneously on the days when the smoke conditions were the worst, they have been separated from the total and given below:

Data obtained simultaneously on days when smoke conditions were worst.[a]

OCTOBER 8, 1913.

Time 11.45 a. m. to 1.30 p. m.
Moderate west or southwest wind.
Rate of sulphur elimination from smelter, 11 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	0.90	1.15
At Corcoran's place almost in direct line behind station 2	.35	.50

OCTOBER 10, 1913.

Time 11.30 a. m. to 4.30 p. m.
Very slight west wind; smoke drifting in path AOC.
Rate of sulphur elimination from smelter, 21 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	0.40	0.80
Station 1	1.00	2.40
At shipyard northwest of station 1	<.20	<.20

NOTE.—The puff of smoke that drifted past station 1 did not extend as far north as the shipyard.

OCTOBER 20, 1913.

Time 2.30 p. m. to 5 p. m.
Very slight west wind; velocity, 2 miles per hour.
Rate of sulphur elimination from smelter, 8 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.10	2.20
Station 1	.60	1.60
Benicia city wharf	<.20	.60

OCTOBER 21, 1913.

Time 11 a. m. to 4 p. m.
West wind; velocity, 3 miles per hour.
Rate of sulphur elimination from smelter, 16 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.10	4.30
Station 1	<.20	.30
Near cemetery north of Benicia	<.20	.20

OCTOBER 27, 1913.

Time 1 p. m. to 4 p. m.
West wind; velocity, less than 2 miles per hour.
Rate of sulphur elimination from smelter, 40 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.10	1.60
Station 1	.80	1.90
At house on Dana place	.70	1.10

[a] See Plates VI and VII.

OCTOBER 28, 1913.

Time 11 a. m. to 3 p. m.
West wind; velocity, less than 2 miles per hour.
Smoke in the path COD.
Rate of sulphur elimination from smelter, 40 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.40	7.10
Station 1	.50	1.50
Near cemetery east of Selby's house	<.20	.20

MAY 10, 1914.

Time 7 a. m. to 10.30 a. m.
West and southwest wind; velocity, 3 miles per hour.
Smoke in the path COD.
Rate of sulphur elimination from smelter, 38 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	0.45	1.00
Station 1	.40	.60
Shipyard	.35	.75

MAY 11, 1914.

Time 12.30 p. m. to 3 p. m.
West and southwest wind; velocity, 4 miles per hour.
Smoke along the paths COD and AOC.
Rate of sulphur elimination from smelter, 45 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.00	3.00
Station 1	.30	.60
City wharf	<.20	.40

MAY 12, 1914.

Time 10 a. m. to 2 p. m.
West or southwest wind; velocity, 4 miles per hour.
Smoke in path COD.
Rate of sulphur elimination, 36 tons per 24 hours.

LOCATION.	Parts of SO_2 per million parts of air. Average.	Maximum.
Station 2	1.50	3.20
Carty's place	.90	1.25

DETERMINATIONS MADE AT TIMES WHEN THE SELBY SMOKE WAS SMELLED, OR WAS SUPPOSED TO HAVE BEEN SMELLED.

The results of determinations of SO_2 at times when the smoke from the Selby smelter was smelled, or was supposed to have been smelled, are given below.

Determinations Made When the Smoke Was Smelled by Chemists of the Commission.

IN AGRICULTURAL AREA.

September 26, 1913.

The smoke was smelled faintly for about 15 seconds by Mr. A. E. Wells and Mr. G. N. Libby. The samples taken at that time at station 2 contained 3.0 parts of SO_2 per million parts of air.

October 21, 1913.

At. 1.50 p. m., Mr. H. L. Long detected the odor of sulphur dioxide. The sample taken at that time contained 4.3 parts of SO_2 per million parts of air.

At 1.55 p. m., the smoke had drifted away from the station, and a sample taken then analyzed 0.4 parts of SO_2 per million parts of air. No smell noted.

At. 2.25 p. m., the smoke drifted past the station, and the concentration of the sulphur dioxide at that time was found to be 2.35 parts per million. Smell noted.

At 2.40 p. m., the smoke had drifted back to the Straits and the air then contained but 1.3 parts of SO_2 per million parts of air. No smell at station 2 noted.

October 28, 1913.

From 11 a. m. to 1 p. m., the smoke was dense around station 2, and was smelled almost continuously between 11 a. m. and 11.30 a. m. The two samples taken during that time analyzed 7.1 parts and 4.9 parts of SO_2 per million parts of air. Again at 12.30 p. m., for about 10 minutes the smoke became strong enough for its detection by smell, and the analysis of the sample gave 5.5 parts of SO_2 per million parts of air.

Note.—Sulphur dioxide was not smelled at station 2 again until May 12, 1914.

May 10, 1914.

At the resort at Glen Cove, Mr. H. L. Long detected the smell of sulphur dioxide as several rather dense puffs of smoke drifted past. However, an analysis of the sample taken during the time one puff was passing gave only 2.3 parts of SO_2 per million parts of air.

May 12, 1914.

At. 12.20 p. m., the smoke was dense around the station; the concentration of the sulphur dioxide in the air was found to be 3.2 parts per million parts of air.

IN BENICIA CITY.

October 10, 1913.

In the morning Mr. J. D. Enas smelled sulphur dioxide slightly at station 1, but was not prepared to take any samples during the few minutes that the smell lasted. At the same time, Mr. G. N. Libby was making determinations at the shipyard, about three-fourths of a mile west and slightly north of station 1, but did not smell the smoke nor detect sulphur dioxide in any sample taken during the morning. At no other time was sulphur dioxide smelled at station 1.

On two other occasions Mr. Enas detected an odor that he believed was from the smelter, but could not identify it as sulphur dioxide or trioxide.

November 20, 1913.

From 4.30 to 5 p. m., Mr. Enas and Mr. Libby just detected this "smelter odor." They were satisfied that the odor was not due to the oil refinery, but at the same time both failed to find any sulphur dioxide in the samples taken then.

October 27, 1913.

The afternoon when the smoke and wind conditions were the worst possible for Benicia, Mr. Libby was taking samples at the Dana place, about 1 mile north of the Vallejo-Benicia Road.

From 4.05 to 4.15 p. m., Mr. Libby detected the odor of sulphur dioxide in passing puffs of smoke. However, the samples taken at that time failed to show the presence of more than 1 part of SO_2 per million parts of air.

The samples taken earlier in the afternoon, when the smoke was not observed or suspected in the vicinity, contained more sulphur dioxide than 1 part per million parts of air. The explanation of this anomaly must be that the puffs of smoke carrying a concentration of sulphur dioxide high enough to be detected by smell were only momentary and had passed before the sample could be taken. Mr. Libby is very sensitive to the smell of sulphur dioxide.

The above-mentioned records are the only recorded times when the smoke could be smelled in Benicia or the surrounding country by the field men of the commission. The writer personally smelled the smoke at station 1 on September 26 and October 21 and 28, 1913, but never detected the odor or taste of sulphur dioxide at any other point or at any other time in the "smoke zone."

Between September 17 and 30, and on several occasions in October, the writer stayed over night in the "smoke zone" for the express purpose of determining whether the wind conditions were such during the night that higher concentrations of sulphur dioxide would be found than during the day. During several evenings and early mornings in that time the atmosphere was calm or a slight west wind prevailed, but the writer detected no odor of sulphur dioxide. The writer spent many late evening hours and early morning hours on the wharf extending out into the straits from Glen Cove, when the wind was seemingly causing the smoke to drift directly from Selby to the point, yet no odor of sulphur dioxide was detected. The conclusion reached was that during the night or early morning hours no abnormal condition existed that would tend to increase the sulphur dioxide content of the air beyond the concentration that would be found under the same wind conditions in the day time. Thus, the sulphur dioxide content found in the atmosphere on October 27 and 28 and on other days when the smoke was gently drifting over the area must be the maximum possible.

DETERMINATIONS MADE AT TIMES WHEN RESIDENTS STATED THAT "SMELTER SMOKE" WAS SMELLED BY THEM.

The results of determinations made at times when residents in the "smoke zone" stated to chemists of the commission that "smelter smoke" was smelled by them are presented below.

SEPTEMBER 17, 1913.

Witness No. 78 claimed to smell the "smelter" at the place where Mr. Libby and Mr. Wells were taking samples. They failed to smell it, however. The maximum analyses of the samples taken at that time was 0.8 part of SO_2 per million parts of air.

SEPTEMBER 25, 1913.

In the middle of the afternoon witness No. 24 stated that he detected the smoke near the shipyard.

From 12.30 to 5.45 p. m. samples were taken at the end of G Street, Benicia.

From 12.30 to 1.30 p. m. the average concentration of sulphur dioxide in the samples was 1.30 parts of SO_2 per million parts of air.

After 1.30 p. m. the breeze from the west freshened and the concentration averaged about 0.6 part of SO_2 per million parts of air, with a maximum concentration of 1 part per million.

SEPTEMBER 30, 1913.

At 11 a. m. witness No. 28 informed Mr. Dutton and Mr. Wells that he smelled the "smelter" distinctly. They were standing at his house at the time. The wind was from the north or northeast and had been from that quarter all the morning, so that no Selby smoke could be in the vicinity. Neither Mr. Dutton nor Mr. Wells could detect any foreign odor whatsoever. At that time Mr. Libby was at the Rose place, and his records state that the wind was from the north or northeast, and show no sulphur dioxide in the atmosphere.

OCTOBER 6, 1913.

Mr. Libby was at Robertson shipyard.

At 3.15 p. m. witness No. 75 stated that he smelled "smelter smoke" distinctly.

The wind was slightly south of west, and although at 2 to 2.30 p. m. Mr. Libby detected slight oil odors, he found no sulphur dioxide in the samples taken between noon and 5 p. m.

OCTOBER 9, 1913.

From 6.40 a. m. to 2.40 p. m. Mr. Libby was taking samples at the Anderson Hotel.

At 7.30 a. m. an elderly gentleman at the hotel stated that the smoke made his eyes smart and water. At that time Mr. Libby detected a very slight oil odor, but samples taken then contained no determinable amount of sulphur dioxide.

OCTOBER 14, 1913.

Mr. Libby was taking samples on the north side of the Vallejo-Benicia Road, about one-half mile west of Burke's saloon.

At 3 p. m. Mr. Libby smelled a slight oil odor and the samples taken then contained about 0.6 part of SO_2 per million parts of air.

A lady residing in the house near this point of sampling stated that she could smell the smelter smoke distinctly.

OCTOBER 15, 1913.

At 9.40 a. m. a lady near the high school in Benicia stated to Mr. Libby that she could "smell the smelter." Mr. Libby could detect a slight odor of oil. A sample taken then contained 0.4 part of SO_2 per million parts of air.

OCTOBER 16, 1913.

At 8 a. m. witness No. 48A stated to Mr. Libby that she could "smell smelter." Mr. Libby could not smell any sulphur dioxide. Samples taken then at her house analyzed 0.4 part of SO_2 per million parts of air.

OCTOBER 22, 1913.

At 8 a. m. witness No. 20A said that he could "smell smelter smoke." Mr. Libby was in a vacant field near the house of witness No. 20 at that time, and could detect no odor. Analyses of samples taken at that time showed the presence of only 0.6 part of SO_2 per million parts of air.

At the times when the smoke was observed by smell by the chemist at station 2 during September, October, and November, the smoke was also observed by the employees of the Pacific Gas & Electric Co. at their transformer station near station 2. No records of their having smelled it at other times were made.

At the Glen Cove resort complaint of "smelter-smoke smell" was made several times. On several occasions after dark the smell of sulphur dioxide was also noted momentarily by witness No 148, who lived there during October and November. The writer was in Glen Cove several nights during September and on many days during October and November when the wind was blowing the smoke directly to Glen Cove or along the above-mentioned path COD, and did not detect the smell of sulphur dioxide.

As stated above, on several evenings in September, the writer stayed for hours out on the wharf projecting into the straits from Glen Cove, when the wind was apparently blowing the smoke directly from Selby, and got no odor of sulphur dioxide.

In May, 1914, Mr. H. H. Bartells detected the smell in Glen Cove on one occasion.

In order to facilitate the work of the commission in the effort to determine the concentration of the sulphur dioxide in the atmosphere at times when the smelter smoke was noticed by people residing in the smoke zone, a number of cards were printed with the form shown below:

Date.....

GENTLEMEN: The smoke from the Selby smelter was noted by myself

or by.....

Date.....

Time.....

Duration of smell.....

Degree of strength of smell—strong...., moderate...., or slight....

Place a cross to indicate the degree of strength.

Signed.....

Between October 4 and 8, 1913, 150 of these cards were given out to about 35 people in the district. Of the 150 cards, only 16 replies were received. Only 8 of the 35 persons to whom cards were given replied at all, and these were all in four families.

One card was received from witness No. 66, complaining of the smoke between 10 a. m. and 12 m. on October 10. This was the time that Mr. Enas thought he smelled sulphur dioxide at the place of

witness No. 78, about 1 mile from the house of witness No. 66. During that time Mr. Libby was at the shipyard, about halfway between the two points, and neither smelled sulphur dioxide nor detected its presence by analytical methods.

Five cards were received stating that the "smoke was strong" at 5 p. m. on that same date, October 10, from two families residing near each other in the residential portion of Benicia. No analyses were made at 5 p. m., as the last had been made by Mr. Libby at the shipyard at 4.30 p. m. At that time his record states the west wind was very slight or calm, but no determinable amount of sulphur dioxide was present in the samples taken.

Witness No. 51A reported "strong smell of smelter smoke" between 9 and 10 a. m. on the 11th of October, at which time there was an east or northeast wind blowing. In this instance the wind was blowing toward the smelter.

On October 16 witness No. 66 reported "strong smell of smoke between 6 and 8 a. m.," the same hour that witness No. 48A reported smelling it to Mr. Libby. As stated previously, Mr. Libby did not then smell it, and samples taken at that time contained only 0.4 part of SO_2 per million parts of air.

Witness No. 20 reported "smell of smoke" at 5 a. m. on the 17th of October. No analyses were made at that time. At 6.45 a. m. Mr. Libby was at the house of witness No. 118, about one-half mile south of the place of witness No. 20 and found less than 0.4 part of SO_2 per million parts of air

Between 3 and 4 p. m. on that same date, the 17th of October, witness No. 66 again reported "smelter smoke." During that time the smoke was observed traveling along the path COD toward station 2, but was not detected by smell there. The maximum concentration found at station 2 during that time was 1.20 parts of SO_2 per million parts of air. Mr. Enas at station 1 reported no smoke around Benicia between 3 and 4 p. m.

On October 18, between 3 and 5 p. m., witness No. 66 again reported "smelter-smoke smell." Up to 3 p. m. of that day the wind had been from the east. At 3 p. m. the east wind died down and the air became calm. No samples were taken after 3 p. m., but both Mr. Long, at Glen Cove, and Mr. Enas, at Benicia, stated that the Selby smoke did not go east along the straits at all during the afternoon.

On October 21 witness No. 20B reported "smelter smoke" between 8 a. m. and 12 m. Mr. Libby made analyses near the cemetery on top of the hill near the place of witness No. 20 from 7.30 a. m. until 2.45 p. m. of that day. His records state that a moderate west wind was blowing and that it was very hazy and foggy during the whole morning. He did not smell sulphur dioxide, and only 4 of the 22 samples taken at that time contained a determinable amount of sulphur dioxide, the maximum being 0.6 part of SO_2 per million parts of air. Mr. Enas

and Mr. Long reported the smoke lying along the Contra Costa shore all the morning.

On October 22 witness No. 20C noted the "smoke" during the morning. Mr. Libby, in a field within 200 yards of the house, found less than 0.4 part of SO_2 per million parts of air. Mr. Enas, at station 1, found a maximum of 0.4 part of SO_2 per million parts of air during that time.

No cards were received after October 22. It should be noted that all cards received stated that the smoke was strong.

It is important to note that on October 27 and 28, when the smelter was discharging a maximum quantity of sulphur dioxide, under directions from the commission, and the wind conditions were the most unfavorable, thereby drifting the smoke directly to Benicia, no complaints by cards were received. The only complaints made were by witness No. 149 and witness No. 132 to the writer. Witness No. 149 resides at the turn of the Vallejo-Benicia road, just west of the shipyard. During the morning of the 27th the smoke had hugged the Contra Costa shore very closely, and had not been noted by our field men on the Solano shore. At noon the smoke started drifting across the straits, and during the greater part of the afternoon was visible around Benicia.

At 3 p. m. witness No. 149 stated that the smoke had been very disagreeable all the morning between 9 and 11 a. m. and had given her a headache. (During this period of time station 1 took nine samples, which averaged 0.3 part of SO_2 per million parts of air. Station 2 took seven samples, which averaged 0.4 part of SO_2 per million parts of air.) At 3 p. m. she could not detect the smoke, though the writer suggested that it might be possible for her to do so.

During the early afternoon of October 27 witness No. 132, who was around the Benicia garage, complained to the writer of the smoke. This was the time when the dense smoke was drifting over Benicia under a very slight westerly breeze, and a concentration of 1.9 parts of SO_2 was determined at station 1.

Of the 30 families or houses supplied with the record cards replies were received from only 4. As all to whom these cards were given expressed a willingness to help us in the investigation to the extent of filling out the cards whenever the smoke was noted, it is reasonable to believe from the fact that no other people sent in cards that none of the others smelled the smoke at any time during the investigation.

Two of the people who did reply noted the smelter smoke on two different occasions when, due to the wind conditions, the smoke could not possibly be in the vicinity of Benicia.

Other reports were received stating that the smoke was noted at times when our field men could not observe it and could find not more than one-half part sulphur dioxide per million parts of air by

analysis of samples taken then. Mr. Libby is especially sensitive to the smell of SO_2; and if he could not detect the presence of SO_2 in Benicia it is rather difficult to believe that others could.

Thus the value of the data from the cards as a record of the times the smoke was present in Benicia is rather doubtful.

Because of the unsatisfactory data obtained with these cards in the effort to determine the sulphur-dioxide concentration when the smell was noted it was decided to carry out some tests to determine the sensitiveness of various persons to the gas. These tests are described in another section of the report.

DETERMINATIONS MADE ON "INSTANTANEOUS SAMPLES" WHEN THE FUMES FROM THE OIL REFINERY WERE NOTED BY THE FIELD MEN OF THE COMMISSION.

At certain stages in the refining of crude oil for asphalt manufacture there are evolved fumes and gases of hydrocarbon compounds probably containing sulphur. These fumes have an extremely disagreeable odor. It has been claimed that prior to 1911 these fumes were allowed to escape from the refinery of the Union Oil Co. at Oleum into the atmosphere and were present in the Selby smoke zone. In 1911 the stills in which the asphaltum is produced were capped, and most of the fumes are now prevented from going out into the air.

It is evident that the oil fumes are not so prevalent in the Selby "smoke zone" now as in former years. However, these fumes still continue to drift at times over Benicia and the rest of the "smoke zone." The writer noted these fumes on many occasions, and on several days they were sufficiently strong to be disagreeable. At White's ranch, on September 26 and on October 25, 1913, the oil fumes were so strong as to be almost nauseating.

An interesting feature in regard to the oil fumes is that they come along over the areas suddenly and frequently are present for a considerable length of time, sometimes for two or three hours.

These frequent and long-time fumigations with the oil fumes, even at the present time when the Union Oil Co. at Oleum has by capping their stills apparently eliminated the emission of these fumes into the air, would indicate that before the stills were capped the oil fumes must have been present very often and in considerable strength.

The odor of the fumes from the oil refineries at Oleum have been confused most certainly with the odor of the sulphur-dioxide gas from the Selby smelter by many of the residents of the area. On several occasions complaints against the smelter fumes were made to the field men when they could not detect any sulphur dioxide by smell, but could detect the odor of the oil fumes. On a few occasions samples of the air were taken and found to contain much less than 1 part SO_2 per million parts of air.

The following table shows the data obtained at times when the smell of oil-refinery fumes was noted by the field men of the commission. These figures do not represent the total number of times the odor was noted, being only a record of the times when the oil odor was noted and samples of the air were taken simultaneously. It will be seen that the sulphur-dioxide content of the air samples taken at times when the oil was smelled does not bear a definite relation to the degree of strength of the oil odor. There was not always a determinable sulphur-dioxide contamination simultaneous with the "oil odor." Conversely, the "oil smell" was not always noted when the determinable amounts of sulphur dioxide were found. Frequently, however, both oil fumes and sulphur dioxide were present at the same time.

Summary of data concerning the "smell of oil."

Date.	Time of day.	Place.[a]	Wind.	Observer.	Degree of smell.	Amount of SO_2 at time of observation.
						Parts per million.
1913.						
Sept. 18	2.20- 2.30	Station 2	Slight W	Wells and Libby.	Slight	0.50
18	3.00- 3.10	do	do	do	do	.35
20	10.50-11.05	do	Strong W	Wells	do	.35
24	10.55-11.05	Station 1	Moderate W	do	do	.30
26	8.00- 9.00	Station 2	Slight W	Wells and Libby.	Strong	1.00
26	2.30- 3.00	do	do	do	do	1.75
30	3.00- 4.00	Rose	Slight SW	Libby	do	2.40
30	4.00- 5.30	do	do	do	Slight	1.95
Oct. 4	11.35-12.00	Carty	West	do	do	.50
8	11.00-12.00	Corcoran	Southwest	do	do	.80
9	6.40- 8.00	Anderson	Slight W	do	do	< .20
14	2.30- 2.45	Passalacqua	do	do	do	.60
14	4.30- 5.00	Station 1	do	Enas	Strong	< .20
15	9.40-10.00	Schoolhouse	do	Libby	Slight	< .20
15	11.30-12.00	do	do	do	Strong	.50
25	10.30- 1.00	Station 2	do	Long and Wells.	Very strong	.40
25	11.15- 1.40	Carty	do	Libby	do	.55
27	3.00- 5.00	Station 1	do	Enas	Strong	.50
28	11.45- 1.00	Catholic cemetery.	do	Libby	do	< .20
29	9.00-10.00	Station 1	do	Enas	Moderate	< .20
Nov. 9	1.00- 1.30	Carty	do	Libby	Slight	< .20
1914.						
Mar. 20	8.00- 9.00	Station 1	Moderate W	Enas	Distinct	.30
22	12.00- 3.00	do	do	do	do	< .20
25	2.00- 3.00	do	Slight W	do	do	.60
27	1.00- 2.00	do	Moderate W	do	do	.30
27	3.00- 4.00	do	do	do	do	.30
Apr. 2	8.15- 8.30	do	do	do	do	< .20
2	3.00- 4.00	do	do	do	do	.50
3	10.00-11.00	do	Strong W	do	do	.20
5	9.30- ([b])	do	do	do	do	.00
5	12.00- ([b])	do	do	do	do	.00
7	9.00-12.00	do	Slight W	do	do	.55
9	4.00-.....	do	West	Bartells	do	.00
11	11.00-12.00	Station 2	SW and N	do	do	.00
11	9.30-10.30	Station 1	do	Enas	do	.00
14	8.00- 9.00	do	Slight W	do	Strong	.60
28	11.00-12.00	Station 2	West	Bartells	do	.00
May 4	1.00- 3.00	Station 1	Southwest	Noreen	Distinct	.00
8	12.00- ([b])	Station 2	West	Bartells	do	.00

[a] See Plates VI and VII.

[b] End of period not definitely known.

DETERMINATIONS OF SO_2 MADE ON "INSTANTANEOUS" SAMPLES TAKEN IN THE SELBY SMOKE STREAM IN CONTRA COSTA COUNTY.

DETERMINATIONS MADE IN CROCKETT.

During October and November, 1913, the Selby smoke was observed many times drifting or lying closely over Crockett. Thus it was thought desirable to determine the sulphur dioxide content of the atmosphere at that place when the Selby smoke was present, especially as the residents of Crockett were not complaining of the smoke. For this purpose a set of apparatus was moved to Crockett in December and placed in a house on the top of the hill near the schoolhouse. Unfortunately, during December the wind was generally from the southeast or east and the Selby smoke was blown toward Crockett only for short periods at long intervals. Thus the greater number of the samples taken (82 out of 87) contained less than 0.2 part sulphur dioxide per million parts of air. After carrying on the tests here for about two weeks the apparatus was dismantled and moved back to station 2 at the White ranch.

Results of determinations made in Crockett.

Date.	Wind.	Number of tests.	Parts of SO_2 per million parts of air.	
			Average.	Maximum.
1913.				
Dec. 3	Southeast	8	<0.20	<0.20
4	Southeast and west	13	< .20	.20
5	do	14	< .20	.40
6	Southeast	9	< .20	< .20
8	do	7	< .20	< .20
9	do	9	< .20	< .20
10	do	8	< .20	< .20
11	do	12	< .20	< .20
12	do	7	< .20	< .20

DETERMINATIONS MADE NEAR SELBY SMELTER AND TORMEY.

On the morning of December 1, 1913, a very strong wind, slightly west of north, was blowing the Selby smoke directly against the hills southeast of the smelter and at times around the "mess house." An attempt was made to determine the sulphur dioxide in the smoke stream at a short distance, about one-quarter mile, from the smelter. The necessary apparatus was carried up on the hill and set up at a point where the smoke stream apparently was striking most often. As shown by the following tabulated results of determinations, the sulphur dioxide content of the air was extremely variable. At times, the sulphur dioxide was smelled strongly for several seconds, and then not again for many minutes. We used the water method of sampling which required about 15 seconds. During the taking of only one sample was the smoke continuously present around the aspirator.

During the morning there were in operation two Dwight & Lloyd machines and one Ropp roaster. Occasionally the acid particles in the smoke stream were felt striking against the face.

Results of determinations made on Dec. 1, 1913, on hill southeast of Selby roaster stack.

[Wind, brisk, west of north.]

Time.	Parts of SO_2 per million parts of air.	Notes.
a. m.		
10.15	2.3	Smoke blown overhead.
10.25	4.5	Smoke around aspirator during part of sampling detected by smell.
10.32	2.0	Smoke high overhead.
10.45	6.8	Smoke around aspirator whole time.
10.49	1.8	Smoke overhead not smelled.
10.55	8.2	Smoke around aspirator about 10 seconds.
11.05	1.0	Smoke high overhead.
11.15	.5	Smoke blown 100 yards to south.
11.20	1.2	Smoke overhead.
11.24	4.5	Smoke blown past aspirator in puffs.
11.32	2.0	Smoke overhead.
11.37	1.0	Smoke blown 100 yards to south.

On December 2, 1913, Mr. Libby obtained the following tabulated results in Tormey and south of Tormey. The wind conditions were about the same as on the preceding day.

Results of SO_2 determinations in Tormey and south of Tormey on Dec. 2, 1913.

Time.	Parts of SO_2 per million parts of air.	Remarks.
a. m.		
10.30	0.0	Samples taken in Tormey directly under smoke stream and three-quarters of a mile south of smelter.
10.37	.3	
10.45	.0	
11.00	.3	
11.10	1.2	
11.20	2.1	
11.40	.9	Samples taken one-quarter mile south of Tormey in smoke stream; occasional odor of sulphur dioxide noticeable.
12.00	.9	
p. m.		
12.10	1.2	
12.20	.4	
1.30	.0	Samples taken on railroad track one-quarter mile south of Tormey.
1.40	.0	
1.50	.0	
2.05	1.5	Samples taken on railroad track close to Tormey, three-quarters of a mile south of smelter stack; occasional odor of sulphur dioxide noticeable.
2.15	2.8	
2.30	.0	
2.35	.3	
2.40	.3	
2.45	.9	Samples taken at point one-half mile south of Tormey; smoke headed directly to point; occasional odor of sulphur dioxide noticeable.
2.55	.6	
3.05	1.8	
3.15	3.6	
3.25	.6	
3.35	.6	

These results show the extent to which the sulphur dioxide content of the air may vary directly in the path of the smoke stream in a brief period of time, owing to the slight changes in the wind direction and velocity.

TOTAL-SULPHUR DETERMINATIONS IN SELBY "SMOKE ZONE."

As a check on the sulphur dioxide determinations from "instantaneous" samples, and also to determine the presence of appreciable amounts of other sulphur compounds, it was decided to determine the total-sulphur content of the atmosphere in the Selby smoke zone. As stated in the description of the method in another part of this report (p. 189), this determination required the aspiration of a relatively large volume of air and occupied considerable time.

In general, each determination extended over a period of about eight hours, although there were several instances where the air was aspirated through the same solution on several successive days.

The total number of these determinations made was 177.

GENERAL SUMMARY OF DATA OBTAINED.

A summary of the data obtained is given in the following tables:

General summary of data obtained in total-sulphur determinations in Selby smoke zone.

Place of sampling.	Number of determinations.	Total sulphur calculated to parts of SO_2 per million parts of air.	
		Average.	Maximum.
Station 1	63	0.21	0.69
Station 2	73	.29	1.50
Auto in Benicia	31	.28	.80
Auto in farming area	10	.22	.40
	177	.26	.....

Comparison of results from total-sulphur determinations with results of determinations from "instantaneous" samples.

Place of sampling.	Parts of SO_2 per million parts of air.	
	Average calculated from total sulphur determinations.	Average of instantaneous samples.
Station 1	0.21	0.20
Station 2	.29	.24
Auto in Benicia	.28	< .20
Auto in farming area	.22	.22

DETERMINATIONS AT STATION 1.

A summary of the total-sulphur determinations made at station 1 is presented below.

Summary of total-sulphur determinations at station 1.

Month.	Number of determinations.	Hours included.	Total sulphur calculated to parts of SO_2 per million parts of air.		
			Average.	Maximum.	Proportional to hours.
September	.....	.....	.....	.....	.....
October	17	133½	0.20	0.44	0.19
November [a]	17	157	.26	.69	.26
March	9	64½	.21	.40	.23
April	13	211	.18	.30	.....
May	7	116	.23	.62	.....
	63	682	.21	.....	.22

[a] Results include results of tests on two days in December.

Parts of SO_2 per million parts of air, average of tests, 0.21.
Parts of SO_2 per million parts of air, average proportional to time, 0.22.
Total number of cubic feet sampled, 1,429.
Average number of cubic feet per sample, 22.8.
Maximum number of cubic feet per sample, 90.8.
Minimum number of cubic feet per sample, 10.3.
Average rate of aspiration, liters per minute, 1.2.

For the purpose of comparison, the total-sulphur determinations made at station 1 have been classified under two heads: (1) Determinations made when the general wind direction was from the west; (2) determinations made when the wind was from a quarter other than the west.

Summary of determinations made under two classes.

Class.	Number of tests.	Total sulphur calculated to parts of SO_2 per million parts of air.	
		Average.	Maximum.
1	36	0.25	0.69
2	27	.16	.44
	63	.....	.....

Comparison of results from total-sulphur determinations with results of determinations from "instantaneous" samples.

Class.	Parts of SO_2 per million parts of air.	
	Total sulphur determinations.	Average of instantaneous samples.
1	0.25	0.23
2	.16	>.20

Results of total-sulphur determinations made at station 1.

OCTOBER, 1913.

Day of month.	Time.	Hours.	Volume of sample.	Total sulphur calculated to parts of SO_2 per million parts of air.	General wind conditions.
			Cu. ft.		
13	7.30–3.30	8	20.2	0.23	West and southwest, brisk.
14	7.00–3.45	8¾	20.0	.07	South and southwest, light.
15	7.45–4.50	9	18.2	.22	Northwest.
16	7.20–3.25	8	18.1	.11	West; slight breeze.
17	7.15–4.00	8¾	20.0	.10	Do.
18	7.35–2.45	7¼	15.8	.44	Northeast wind.
20	7.30–4.00	8½	18.0	.22	Northeast, a. m.; west, p. m.
21	8.10–3.55	8	14.2	.10	West wind.
22	7.25–4.00	8½	20.2	.07	West wind; brisk.
24	7.15–3.40	8½	22.5	.27	Northwest wind; brisk.
25	10.15–4.50	6½	16.2	.20	Slight west wind.
26	9.40–4.30	7	18.0	.08	East and south wind; brisk.
27	7.20–4.20	9	18.3	.35	Slight west breeze.
28	9.05–2.10	5	8.0	.38	Do.
29	8.50–4.50	8	16.7	.39	Strong west breeze.
30	7.55–3.10	8¼	16.4	.12	Northwest and west breeze.
31	8.00–2.35	6½	14.3	.00	Calm or slight west.

NOVEMBER, 1913.

2	8.45– 2.45	6	12.2	0.38	Slight west or northwest wind.
3	8.00– 2.45	6¾	14.3	.35	Slight west or north wind.
4	8.30– 3.45	7¼	16.4	.24	South or southeast.
6	7.45– 5.15	9½	20.3	.24	Slight southeast and variable.
7	7.45– 2.45	7	14.2	.28	Northeast and calm.
8	7.30– 3.15	7¾	18.4	.16	Northeast.
10	7.50– 4.20	8½	18.4	.45	Slight west wind.
11	10.40– 4.00	8	18.4	.14	Southeast and east.
12	1.00– 3.40				
13	8.30– 12.00	9¾	22.8	.16	North or northeast.
14	8.30– 2.45				
15	7.35– 4.05	8½	20.8	.27	West and northwest.
16	1.15– 5.00	3¾	10.5	.69	West.
19	8.05– 4.05	8	20.7	.00	Northwest.
20	8.30–12.00	3½	10.3	.29	Northwest and west.
21	8.30– 4.30	8	18.7	.24	Slight west.
22	9.30– 4.15	6¾	14.5	.28	Do.
24	7.30– 3.30	36½	95.4	.12	East or southeast three days. West or northwest two days.
25	8.25– 4.35				
26	8.00– 2.35				
28	7.25– 3.35				
29	9.25– 4.00				

DECEMBER, 1913.

1	7.40– 2.40	11	27.0	0.05	North or northeast wind.
3	7.40–11.40				

MARCH, 1914.

21	12.45–5.15	4½	10.2	0.10	West wind.
23	10.00–4.30	6½	14.5	.02	Southwest to northwest.
24	7.45–4.25	8¾	20.5	.40	South to southwest.
25	8.00–4.00	9	22.5	.16	Southwest to west.
26	8.00–5.00	9	20.5	.24	West.
27	8.05–5.05	9	20.5	.24	Do.
28	8.00–2.30	6½	16.0	.25	South.
30	9.00–1.30	4½	10.0	.30	South and southwest.
31	8.05–2.40	6½	16.0	.17	South or southeast.

Results of total-sulphur determinations made at station 1—Continued.

APRIL, 1914.

Day of month.	Time.	Hours.	Volume of sample.		Total sulphur calculated to parts of SO_2 per million parts of air.	General wind conditions.
			Cu. ft.			
1	7.45–3.35	7¾	18.0		0.17	East.
2	7.45–4.35	8¼	22.5	40.5	.28	West.
3	8.45–5.00	9	18.0			
4	8.30–3.30	7	16.0		.12	Southeast.
5	8.35–3.00	6½	12.0	28.0	.09	Southwest.
6	7.40–2.40	7	16.0			
7	7.55–2.30	6½	14.0			
8	7.40–5.05	9¼	20.0			
9	7.55–5.20	9¼	20.0	90.8	.14	West and southwest.
10	7.45–4.20	8½	20.0			
11	5.15–2.35	7½	16.8			
13	5.35–2.35	8	20.6	36.6	.15	West.
14	7.15–2.00	6½	16.0			
15	7.40–5.00	9	14.0	30.0	.20	Do.
16	8.25–4.35	8	16.0			
17	7.20–4.40	9¼	18.0		.14	Southeast.
18	10.00–4.50	7	14.0	28.0	.30	Do.
19	10.00–4.45	7	14.0			
20	8.30–3.30	7	16.0			
21	8.00–5.00	9	18.0	50.0	.09	South or west or southwest.
22	8.55–4.45	8	16.0			
23	8.45–4.45	7	16.0	30.0	.30	West.
24	9.05–4.00	7	14.0			
27	7.00–3.45	8¾	18.0	34.0	.25	West and southwest.
28	5.45–2.30	6	16.0			
29	8.00–4.45	9	18.0	32.0	.08	Northwest.
30	7.00–1.40	6¾	14.0			

MAY, 1914.

1	8.00–4.45	8	18.0			Northwest.
2	6.00–2.45	7	16.0	48.0	0.12	West.
3	10.00–4.45	7	14.0			Southwest.
4	6.00–2.45	8¾	16.0		.06	Do.
5	10.00–4.45	7	14.0	30.0	.32	Southwest and northwest.
6	6.00–2.00	8	16.0			
7	10.00–5.45	8	16.0	34.0	.62	West.
8	8.00–4.45	9	18.0			
9	6.00–2.45	8¾	18.0	36.0	.20	Southwest, west.
10	7.15–4.00	9	18.0			
11	8.15–5.00	9	18.0	36.0	.24	Southwest to northwest.
12	5.30–2.15	9¼	18.0			
13	8.00–4.45	8¾	18.0	36.0	.05	Southwest.
14	8.00–4.45	8¾	18.0			

In the following table it will be noted that some of the samples contained relatively large quantities of SO_2 compared with the average of the "instantaneous" samples. These high figures may be due to sulphates getting into the solutions in spite of all the care used in handling the samples.

Total-sulphur determinations at station 1 made when the general wind direction was from the west or slightly south or north of west.

Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.	Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.
	Tons.				*Tons.*		
Oct. 13	14	0.23	0.15	Apr. 7	27		0.50
Oct. 15	14	.22	<.20	Apr. 8	32		<.20
Oct. 16	2	.11	<.20	Apr. 9	31	0.14	<.20
Oct. 17	18	.10	<.20	Apr. 10	27		.22
Oct. 21	16	.10	<.20	Apr. 11	28		<.20
Oct. 22	12	.07	<.20	Apr. 13	27		.20
Oct. 25	9	.20	<.20	Apr. 14	20	.15	.30
Oct. 27	40	.35	.50	Apr. 15	16		.25
Oct. 28	40	.38	.40	Apr. 16	17	.20	.30
Oct. 29	38	.39	<.20	Apr. 23	33		.30
Oct. 30	16	.12	.20	Apr. 24	28	.30	.40
Oct. 31	11	0	<.20	Apr. 27	25		.50
Nov. 2	10	.38	.25	Apr. 28	21	.25	.40
Nov. 3	19	.35	.20	May 1	27		.30
Nov. 10	33	.45	.30	May 2	24	.12	.25
Nov. 15	16	.27	<.20	May 3	26		.60
Nov. 16	14	.69	.20	May 5	29		.50
Nov. 20	22	.29	<.20	May 6	41	.32	.45
Nov. 21	35	.24	<.20	May 7	40		.50
Nov. 22	36	.28	.20	May 8	36	.62	.30
Mar. 21	31	.10	<.20	May 9	25		.25
Mar. 24	18	.40	<.20	May 10	38	.20	.35
Mar. 25	21	.16	<.20	May 11	45		.20
Mar. 26	22	.24	<.20	May 12	36	.24	.20
Mar. 27	28	.24	<.20				
Apr. 2	23	.28	.25				
Apr. 3	27						

Total-sulphur determinations at station 1 made when general wind direction was from a quarter other than the west.

Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.	Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.
	Tons.				*Tons.*		
Oct. 14	16	0.07	<0.20	Mar. 23	19	0.02	<0.20
Oct. 18	17	.44	<.20	Mar. 28	24	.25	<.20
Oct. 20	8	.22	.30	Mar. 30	30	.30	<.20
Oct. 24	13	.27	.20	Mar. 31	20	.17	<.20
Oct. 26	30	.08	<.20	Apr. 1	23	.17	<.20
Nov. 4	17	.24	<.20	Apr. 4	25	.12	<.20
Nov. 6	11	.24	<.20	Apr. 5	23	.09	<.20
Nov. 7	14	.28	<.20	Apr. 6	27	.....	.....
Nov. 8	11	.16	<.20	Apr. 17	21	.14	.....
Nov. 11	12	.14	<.20	Apr. 18	24	.30	<.20
Nov. 12	14	.....	.....	Apr. 19	26	.....	<.20
Nov. 13	18	.16	<.20	Apr. 20	27	.....	<.20
Nov. 14	18			Apr. 21	22	.09	<.20
Nov. 19	16	.....	<.20	Apr. 22	21	.....	.35
Nov. 24	0			Apr. 29	23	.08	<.20
Nov. 25	0			Apr. 30	26	.....	<.20
Nov. 26	0	.12	<.20	May 4	28	.06	<.20
Nov. 28	0			May 13	22	.05	<.20
Nov. 29	39			May 14	26	.....	<.20
Dec. 1	23	.05	<.20				
Dec. 3	11						

Summary of total-sulphur determinations at station 2.

Month.	Number of determinations.	Hours included.	Total sulphur calculated to parts of SO_2 per million parts of air.		
			Average.	Maximum.	Proportional to hours.
September	5	28	1.10	1.50	1.03
October	18	147	.50	1.38	.52
November	15	161	.11	.45	.12
March	12	102	.15	.44	.13
April	16	214	.14	.26	.13
May	7	101	.25	.55	.11
	73	753	.285		

Total number of cubic feet sampled, 1,325.
Average number of cubic feet per sample, 18.2.
Maximum number of cubic feet per sample, 98.
Minimum number of cubic feet per sample, 5.8.
Average length of time per cubic foot, 34 minutes.
Average rate of aspiration of sample, liters (about) per minute, 1.2.
Parts of SO_2 per million parts of air, average proportional to time, 0.24.

The total-sulphur determinations made at station 2 have been segregated as follows:

1. Determinations made when the wind was from the west, and during part of the sampling period the smoke was headed directly to the station in the path COD (Pl. VI).

2. Determinations made when the wind was from the west, and the smoke was confined mostly to the path AOC.

3. Determinations made when the wind was from a quarter other than the west.

Summary of classified results of total-sulphur determinations at station 2.

Class.	Number of tests.	Total sulphur calculated to parts of SO_2 per million parts of air.	
		Average.	Maximum.
1	20	0.72	1.50
2	25	.09	.25
3	28	.15	.44
	73		

Comparison of results from total-sulphur determinations with results of determinations from "instantaneous" samples.

Class.	Average parts of SO_2 per million parts of air.	
	Calculated from total sulphur determinations.	Average of "instantaneous" samples.
1	0.72	0.60
2	.09	$<$ .20
3	.15	$<$ .20

Results of total-sulphur determinations made at station 2.

SEPTEMBER, 1913.

Day of month.	Time.	Hours.	Volume of sample.	Total sulphur calculated to parts of SO_2 per million parts of air.	General wind conditions.
			Cubic feet.		
18	10.15–12.30	2¼	5.8	0.30	Slight east and west wind.
18	2.00– 6.50	4¾	10.5	1.30	Slight west wind.
20	7.15–12.45	5	13.0	1.20	Moderate west wind.
22	11.50– 5.45	6	15.6	1.50	Slight west wind.
26	7.45– 5.45	10	14.8	.85	Do.

OCTOBER, 1913.

9	8.10– 4.40	8½	16.1	1.03	Slight breeze from west.
10	8.10– 4.10	8	16.0	.83	
11	7.15– 2.45	7½	16.0	.29	Slight breeze from west two hours; then from north.
13	11.15– 5.45	6½	12.1	.37	Strong wind from west.
14	8.00– 4.45	8¾	19.5	.43	Moderate wind from west.
15	8.00– 4.45	8¾	20.1	.33	
16	8.00– 4.50	8¾	15.9	.23	Slight wind from west.
17	8.20– 4.50	8½	15.8	.20	Smoke blown up channel.
18	7.00– 3.00	8	15.8	.00	Wind from north and northeast.
19	7.00– 3.30	8½	17.7	.10	
20	7.25– 4.55	9½	17.7	.60	Wind from north and northeast in the morning; from smelter in afternoon.
21	7.30– 5.00	9½	20.2	1.25	Slight wind from direction of smelter.
24	8.00– 4.45	8¾	18.3	.12	Wind from northwest.
25	8.00–11.00	3	8.3	.00	
27	9.00– 4.45	7¾	16.2	.71	Northwest in forenoon; west in afternoon.
28	7.30– 4.30	9	20.1	1.38	Northwest in forenoon; slight west wind in afternoon.
29	7.30– 4.30	9	20.4	.82	Strong west and southwest wind.
31	7.35– 4.35	9	17.8	.23	Slight southwest or southeast wind.

NOVEMBER, 1913.

3	9.15–5.15	8	16.4	0.18	Southwest wind.
5	7.30–4.15	8¾	18.5	.00	South or southwest wind.
6	7.30–4.15	8¾	18.3	.04	South or northwest wind.
7	7.30–4.30	9	18.3	.18	Southeast wind.
8	7.00–3.00	8	16.2	.10	North or northeast wind.
10	9.00–4.50	7¾	16.4	.00	Smoke along channel and bluffs to east.
11	7.30–4.30	9	18.4	.08	South or southeast wind.
12	8.30–4.30	8	16.5	.02	Southeast wind.
13 14	8.30–4.15 8.00–4.30	16¼	25.7	.05	Northeast wind. Southeast wind.
17 19	9.00–4.45 8.00–4.30	16¼	32.7	.16	Variable; seldom toward station.
20 21	7.30–4.30 8.30–4.30	17	30.3	.19	Brisk general northwest wind.
22	8.00–4.15	8¼	14.2	.45	Moderate west wind.
24 25 26	9.00–4.30 8.00–3.00 8.30–3.00	21	40.2	.14	South or southeast wind.
28	2.00–5.00	3	5.7	.00	Slight northwest breeze.
29 30	8.30–2.00 10.00–4.30	12	22.8	.06	Northwest or north wind.

Results of total-sulphur determinations made at station 2—Continued.

MARCH, 1914.

Day of month.	Time.	Hours.	Volume of sample.	Total sulphur calculated to parts of SO_2 per million parts of air.	General wind conditions.
			Cubic feet.		
19	8.45–5.45	9	10.0	0.10	East wind.
20	8.20–5.15	9	10.0	.16	West wind; smoke path AOC.[a]
21	8.30–3.45	7	14.0	.00	West wind; smoke path AOC.[a]
23	10.10–5.30	7	14.0	.00	Slight west wind; smoke path AOC.[a]
24	8.10–5.20	9	20.0	.05	Brisk west wind.
25	8.20–5.25	9	20.0	.05	Brisk southwest wind.
26	8.20–5.25	9	21.0	.11	Brisk northwest wind.
27	8.20–5.20	9	20.5	.28	West and northwest wind.
28	8.25–5.25	9	20.0	.00	Southwest wind.
29	8.50–5.20	8½	20.5	.44	Southwest and southeast wind.
30	8.25–4.15	8	18.3	.24	Southeast and southwest wind.
31	8.25–4.50	8½	18.3	.33	Southeast wind.

APRIL, 1914.

1	8.35–5.20	9	20.3	0.25	East wind.
2	8.35–5.15	8½	20.0	.18	East and slightly west wind.
3	8.35–2.00	5½	14.0	.19	Slight southwest wind.
4	9.25–3.55	6½	16.0	.25	Strong southeast wind
6	9.30–5.25	8	18.0	.26	Slight southwest wind.
7	9.10–5.20	8	16.0	.25	Slight west wind, along path AOC.[a]
8	8.35–5.20	9	20.0	.17	Slight southwest and east wind.
9	8.35–5.20	8½	18.0	.06	Strong southwest or west wind.
10	8.35–5.20	9	20.0	.04	Strong west wind; path AOC.[a]
11	8.30–5.30	9	20.0	.04	Slight west wind; path AOC.[a]
12	8.45–5.20	8½	20.0		
13	8.30–5.30	9	20.0	.12	Do.
14	8.40–3.10	6½	14.0		
17	8.50–5.25	8½	18.0	.14	Southeast wind; path AOC.[a]
18	8.40–3.40	7	18.0		
20	10.20–5.25	7	16.0	.11	Strong west and southwest wind.
21	8.40–5.10	8	20.0		
22	8.35–5.10	8½	20.0	.07	Strong west wind.
23	8.45–5.15	8½	20.0		
24	8.40–5.20	8¾	20.0	.03	Do.
25	8.30–5.20	9	20.0		
26	8.30–4.05	7½	18.0		Do.
27	8.45–5.30	8¾	20.0		Do.
28	8.35–5.25	9	20.0	.13	Do.
29	8.40–5.25	9	20.0		Slight east wind.
30	8.20–5.20	9	20.0		Do.

MAY, 1914.

1	8.35–5.00	8½	20.0	0.06	Strong west and northwest wind.
2	8.40–3.45	7	18.0		
4	10.30–5.10	6½	14.0	.15	Strong west wind.
5	8.50–5.15	8½	20.0		
6	8.40–5.00	9¼	20.0	.11	Do.
7	5.30–1.50	8½	20.0		
8	8.40–5.00	9½	20.0	.23	Do.
9	5.30–1.50	8½	20.0		
10	8.40–5.50	9¼	20.0	.50	Slight west wind.
11	5.40–2.20	9	20.0	.55	Do.
12	9.15–5.20	8	18.0	.13	Strong west wind.
13	5.30–2.00	8½	20.0		

[a] See Plate VI.

Total-sulphur determinations at station 2, classified according to wind conditions.

WIND FROM THE WEST, AND THE SMOKE, DURING PART OF THE SAMPLING PERIOD, HEADED DIRECTLY TO STATION IN PATH COD.[a]

Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.	Date.	Rate of sulphur elimination from smelter per 24 hours.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of "instantaneous" samples.
	Tons.				*Tons.*		
Sept. 18	32	1.30	1.25	Oct. 21	16	1.25	0.80
Sept. 20	31	1.20	.25	Oct. 27	40	.71	.80
Sept. 22	26	1.50	1.05	Oct. 28	40	1.38	1.25
Sept. 26	17	.85	1.15	Oct. 29	38	.82	.80
Oct. 9	11	1.03	.55	Nov. 22	36	.45	.35
Oct. 10	21	.83	.55	Apr. 2	23	.18	.22
Oct. 13	14	.37	.30	May 8	36	.23	.25
Oct. 14	16	.43	.50	May 9	25		
Oct. 15	14	.33	.20	May 10	38	.50	.40
Oct. 16	2	.23	< .20	May 11	45	.55	.65
Oct. 20	8	.60	.65				

WIND FROM THE WEST, AND SMOKE CONFINED MOSTLY TO PATH AOC.[a]

Oct. 17	18	0.20	<0.20	Apr. 11	28	0.04	<0.20
Oct. 24	13	.12	.20	Apr. 12			
Oct. 25	9	.00	< .20	Apr. 13	20	.12	< .20
Nov. 6	11	.04	< .20	Apr. 14			
Nov. 10	33	.00	< .20	Apr. 22	27	.07	< .20
Nov. 20	22	.19	.25	Apr. 23			
Nov. 21	35			Apr. 24	29	.03	< .20
Nov. 28	.....	.00	< .20	Apr. 25			
Nov. 29	39	.06	< .20	Apr. 26	.....	.....	.....
Nov. 30	33			Apr. 27	.....	.....	.....
Mar. 20	24	.16	< .20	Apr. 28	24	.13	< .20
Mar. 21	31	.00	< .20	May 1	.....	.....	.....
Mar. 23	19	.05	< .20	May 2	25	.06	< .20
Mar. 24	18	.05	< .20	May 4	.....	.....	.....
Mar. 26	22	.11	< .20	May 5	29	.15	< .20
Mar. 27	28	.28	< .20	May 6	41	.11	< .20
Apr. 7	27	.25	< .20	May 7			
Apr. 10	27	.04	< .20	May 12	36	.13	.30
				May 13			

GENERAL WIND DIRECTION FROM OTHER QUARTERS THAN THE WEST.

Oct. 11	17	0.29	0.20	Mar. 25	21	0.05	<0.20
Oct. 18	17	.00	< .20	Mar. 28	24	.00	< .20
Oct. 19	10	.10	< .20	Mar. 29	20	.44	< .20
Oct. 31	11	.23	< .20	Mar. 30	30	.24	< .20
Nov. 3	19	.18	.20	Mar. 31	20	.33	< .20
Nov. 5	19	.00	< .20	Apr. 1	23	.25	< .20
Nov. 7	14	.18	< .20	Apr. 3	27	.19	< .20
Nov. 8	11	.10	< .20	Apr. 4	25	.25	< .20
Nov. 11	12	.08	< .20	Apr. 6	28	.26	< .20
Nov. 12	14	.02	< .20	Apr. 8	32	.17	< .20
Nov. 13	18	.05	< .20	Apr. 9	31	.06	< .20
Nov. 14	18			Apr. 17	21	.14	< .20
Nov. 17	17	.16	< .20	Apr. 18	25		
Nov. 19	16			Apr. 20	27	.11	< .20
Nov. 24				Apr. 21	23		
Nov. 25	.....	.14	< .20	Apr. 29	23	.13	< .20
Nov. 26				Apr. 30	26		
Mar. 19	27	.10	< .20				

[a] See Plate VI.

Total-sulphur determinations made by automobile laboratory inside Benicia city limits.

Date.	Place.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average SO_2 content of instantaneous samples.	General wind notes.
1913.				
Sept. 17	Fisher's	1.02	0.60	Gentle west wind.
Sept. 18	Carty's	.00	.20	Gentle west to northwest wind.
Sept. 24	Fisher's	.40	.35	Moderate west wind.
Sept. 25	West end of G Street	.43	.70	Do.
Sept. 27	.....do	.47	.30	Do.
Oct. 4	Carty's	.20	<.20	Moderate west and northwest wind.
Oct. 6	Shipyard	.10	<.20	Light southwest wind.
Oct. 7	K and Main Streets	.15	<.20	Light west or southwest wind.
Oct. 8	Rose Place	.40	.30	Light west wind.
Oct. 8	Anderson Hotel	.60	.....	Do.
Oct. 9	.....do	.10	<.20	Moderate west wind.
Oct. 10	Shipyard	.65	<.20	Very light west wind; calm.
Oct. 14	Passalacqua	.15	.40	Do.
Oct. 15	Schoolhouse	.20	<.20	Do.
Oct. 16	Passalacqua	.20	<.20	Do.
Oct. 17	K Street near Prince's	.25	.20	Do.
Oct. 20	Benicia wharf	.00	<.20	Northwest wind.
Oct. 22	Eben Selby	.35	.30	Light west wind.
Oct. 24	Carty's	.05	<.20	Do.
Oct. 25	Shipyard	.00	.20	Do.
Oct. 27	Dana	.77	.35	Do.
Oct. 28	Cemetery	.15	<.20	Do.
Oct. 29	Carty's	.30	<.20	Strong west wind.
Nov. 4	Shipyard	.20	<.20	Calm or slight west wind.
Nov. 7	City wharf	.75	<.20	East wind (smoke from Mountain Copper Co.).
Nov. 8	Burke's saloon	.05	<.20	Slight west wind; strong.
Nov. 9	Anderson Hotel	.10	<.20	Strong west wind.
Nov. 19	Tannery	.30	<.20	Light northwest wind.
Nov. 21	Anderson Hotel	.30	<.20	Light west wind.
Nov. 22	Tannery	.00	<.20	Strong west wind.
Nov. 25 Nov. 26	Arsenal	.30	<.20	East wind (smoke from Mountain Copper Co.).

Number of tests, 31.
Total hours, 196.
Average parts of SO_2 per million parts of air proportional to hours, 0.28.
Average parts of SO_2 per million parts of air proportional to tests, 0.28.
Maximum SO_2 content, parts per million parts of air, 1.
Average parts of SO_2 per million parts of air from instantaneous samples, less than 0.20.

Total-sulphur determinations made by automobile laboratory in the farming districts between Benicia and Vallejo.

Date.	Place.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average parts of SO_2 per million parts of air, instantaneous samples.	General wind notes.
1913.				
Sept. 30	Rose house	0.15	0.53	North wind, then west.
Oct. 2	Brazil's house	.35	.24	Light west wind.
Oct. 3	Rose house	.10	<.20	Strong west wind.
Oct. 5	Dos Reis Cove	.30	<.20	Strong southwest wind.
Oct. 13	.....do	.15	<.20	Do.
Oct. 30	Clynes Cove	.40	<.20	Strong northwest wind.
Nov. 3	Midway saloon	.35	<.20	Calm.
Nov. 5	Dos Reis house	.20	<.20	Strong southwest wind.
Nov. 6	Brazil's house	.05	<.20	Light west or southwest wind.
Nov. 17	Dos Reis house	.15	<.20	Light southeast wind.

Total number of tests, 10.
Total number hours during tests, 54½.
Average parts of SO_2 per million parts of air, proportional to hours, 0.22.
Average parts of SO_2 per million parts of air, proportional to tests, 0.40.
Average parts of SO_2 per million parts of air, instantaneous samples 0.22.

SULPHUR DIOXIDE PRESENT IN THE ATMOSPHERE OUTSIDE THE SELBY SMOKE ZONE.

"Instantaneous" samples for SO_2 determinations were taken in the following sections:

1. Ocean Beach, San Francisco.
2. Business section, San Francisco.
3. Oakland and Berkeley.
4. Richmond and vicinity.
5. Martinez and Avon (i. e., in smoke zone of the Mountain Copper Co.).

DETERMINATIONS OF SULPHUR DIOXIDE PRESENT IN AIR AT OCEAN BEACH, SAN FRANCISCO, CAL.

Fifteen samples were taken along the Beach Road, south of the Cliff House, on September 1, 3, and 11, 1913, when there was a strong wind blowing off the ocean. None of these 15 samples contained determinable quantities of sulphur dioxide, there being present less than 0.2 part of SO_2 per million parts of air.

DETERMINATION OF SULPHUR DIOXIDE PRESENT IN ATMOSPHERE IN SAN FRANCISCO.

A total of 173 determinations were made in San Francisco. The average result was 0.3 part of SO_2 per million parts of air, the maximum being 1.8 parts per million parts of air. Between September 1 and 15, 1913, 74 determinations were made by A. E. Wells. At this period the air of the city was extremely smoky or foggy during the early morning hours. Along about the middle of the forenoon each day a slight westerly breeze would start to blow, gradually increasing in strength until at noon it would be brisk. As the wind velocity increased the smoke and fog were dissipated, and after 11 o'clock each day the air was very clear. The comparatively calm wind conditions in the early morning hours allowed an appreciable increase of the sulphur dioxide content of the air from the combustion of fuel in the city. Thus, the samples taken early in the morning contained the greatest amounts of sulphur dioxide. The sample containing the highest sulphur dioxide content (1.80 parts SO_2 per million parts of air) was taken at 9.30 a. m. on September 3, just north of the Southern Pacific tracks near Third and Townsend Streets. At the time this sample was taken the air was nearly calm and very smoky. At 10 a. m. the wind started to blow slightly, clearing the atmosphere somewhat, and the sulphur dioxide content decreased to 0.75 part per million parts of air. At noon the sulphur dioxide content was 0.30 part per million parts of air.

Again on September 6 the same atmospheric conditions existed as on the 3d. Samples were taken near the warehouse of the Pacific

Hardware & Steel Co., near King and Eighth Streets. The first two samples taken contained 1.60 parts of SO_2 per million parts of air. By 11 a. m. a west wind had sprung up, the air became clearer, and the sulphur dioxide content decreased. At 1 p. m. the sulphur dioxide content was only 0.20 part per million parts of air.

During February and March, 1914, determinations were made in San Francisco by Mr. G. N. Libby. During this period there were several mornings when the air was calm, and at these times the sulphur dioxide content was found to be as high as 0.75 part per million parts of air.

Summarized briefly, the sulphur dioxide content of the air in the business section of San Francisco was found to be as high as 1.80 parts per million parts of air during calm, smoky conditions. Under ordinary wind conditions, the sulphur dioxide did not average more than 0.30 part SO_2 per million parts of air.

Summary of tests in business section of San Francisco.

[Total number of tests, 173; average parts SO_2 per million parts of air, 0.29.]

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	79	45.7
.2 to .4	50	29.0
.4 to .6	23	13.3
.6 to .8	16	9.2
.8 to 1.0	2	1.1
1.0 to 1.5	1	.6
1.5 to 2.0	2	1.1
	173	100.0

Detailed results of tests in business section of San Francisco.

SEPTEMBER, 1913.

Day of month.	Place.	Notes.	Number of samples.	Parts of SO_2 per million parts of air.	
				Average.	Maximum.
3	North of Southern Pacific tracks, Third Street.	Smoky at first, clearing later	5	0.80	1.80
3	Appraisers' building	Clear	2	.30	.30
4	do	do	2	.35	.40
5	Corner second and Harrison Streets.	Slightly smoky	10	.30	.50
5	China Basin	Generally clear, occasional engine smoke.	10	.50	.80
6	Warehouse, Pacific Hardware & Steel Co.	Smoky	9	.73	1.70
6	Near gas tanks, Embarkadero	do	2	.90	1.00
8	do	do	6	.25	.55
8	Viaduct, east of Southern Pacific yards.	do	8	.40	.65
9	Appraisers' building	Clear	10	.35	.50
15	Corner Harrison and Sixteenth Streets.	Smoky	5	.60	.80
15	Top of hill, Eighteenth Street	Clear	5	.20	.20
			74	.45	

Detailed results of tests in business section of San Francisco—Continued.

FEBRUARY, 1914.

Day of month.	Place.	Notes.	Number of samples.	Parts of SO_2 per million parts of air.	
				Average.	Maximum.
11	Appraisers' building	Calm, smoky	6	0.35	0.75
11	Corner Sixteenth and Illinois Streets.	Calm, clear	6	.30	.75
			12	.30	.....

MARCH, 1914.

3	On Arkansas Street, west of General Electric Co. plant.	Light southeast wind	4	<0.20	<0.20
3	Corner Kentucky and Fifteenth Streets.	.....do	3	< .20	< .20
4	King and Fourth Streets	.....do	4	< .20	.50
4	Corner Seventeenth and Mississippi Streets.	Clear	10	< .20	< .20
5	Corner Fifteenth and Potrero Streets.	Smoky at the start, clearing	5	.25	.50
5	Corner Fifteenth and San Bruno Streets.	Calm	7	< .25	.50
6	Fifteenth Street, between Potrero and San Bruno.	Northeast wind	14	< .25	.50
7	Seventh and Berry Streets at Southern Pacific tracks, near Scott, Magner & Miller.	Calm	13	.40	.75
10	Corner Sixteenth and Bryant Streets.	West wind, clear	15	< .25	< .25
19	Near gas works on East Street	West wind	12	< .25	.50
			87	< .20	.....

Examples of variation of sulphur dioxide content of the air during the day in San Francisco.

SEPTEMBER 3, 1913.

DETERMINATIONS MADE NORTH OF THE SOUTHERN PACIFIC CO.'S TRACKS, BETWEEN THIRD AND FOURTH STREETS.

Time.	Notes.	Parts of SO_2 per million parts of air.
a. m.		
9.30	No wind; very smoky	1.80
10.05	Slight southwest wind; slightly smoky	.70
10.30	Slight southwest wind; clearer air	.80
11.05	Moderate west wind; clear	.25
p. m.		
12.25	Brisk west wind; clear	.40

DETERMINATIONS MADE AT APPRAISERS BUILDING.

p. m.		
2.05	Brisk west wind; clear	0.30
4.30	Do	.30

Examples of variation of sulphur dioxide content of the air during the day in San Francisco—Continued.

SEPTEMBER 6, 1913.

DETERMINATIONS MADE NEAR WAREHOUSE OF PACIFIC HARDWARE & STEEL CO. NEAR INCINERATOR.

Time.	Notes.	Parts of SO_2 per million parts of air.
a. m.		
10.55	Very slight east wind; very smoky	1.70
11.10	Do	1.40
11.45	West wind springing up; clearer	.70
12.00	Do	.70
p. m.		
12.25	Brisk west wind; clear	.40
12.45	Do	.50
12.55	Do	.40
1.05	Do	.30
1.25	Do	.40

DETERMINATIONS MADE IN OAKLAND AND BERKELEY.

During January and February 148 determinations were made in Oakland and Berkeley. The maximum sulphur dioxide contamination (1 part SO_2 per million parts of air) was found in the path of the smoke from the Southern Pacific Co.'s roundhouse and near the gas plant near Market and First Streets. Outside the line of smoke from this source the air was found to contain less than 0.2 part of SO_2 per million parts of air.

Summary of results of tests made in Oakland and Berkeley.

[Number of tests, 148; average SO_2, less than 0.20 part per million parts of air.]

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	117	79.0
.2 to .4	19	12.8
.4 to .6	8	5.4
.6 to .8	2	1.4
.8 to 1.0	2	1.4
	148	100.0

Detailed results of tests made in Oakland and Berkeley.

DECEMBER, 1913.

Day of month.	Place.	Notes.	Number of samples.	Parts of SO_2 per million parts of air.	
				Average.	Maximum.
23	Grant Street, Berkeley	Slight west wind	12	<0.20	0.20

Detailed results of tests made in Oakland and Berkeley—Continued.

JANUARY, 1914.

Day of month.	Place.	Notes.	Number of samples.	Parts of SO_2 per million parts of air.	
				Average.	Maximum.
2	In line Southern Pacific R. R. Co. roundhouse smoke, near Adeline Street.	Light south wind	3	0.70	1.00
2	One-half block north of gas works on Market and First Streets.	do	8	.60	1.00
3	Center and Third Streets	Southeast wind; clear	5	<.20	<.20
3	Third and Linden Streets, near gas plant, under smoke.	Light southeast wind; clear	6	.20	.80
3	Market and Seventh Streets	do	10	<.20	.20

FEBRUARY, 1914.

1	Alameda Bridge	Very clear day; smoke high; west wind.	14	<0.20	<0.20
3	Near Southern Pacific Mole and corner Jefferson and Third Streets.	Smoke high; wind south and west.	12	< .20	< .20
4	Third and Clay Streets. Under Southern Pacific and gas plant smoke.	Wind south and west	17	.20	.60
5	Harrison and Third Streets	Light west wind; clear	12	< .20	< .20
6	University Avenue and Berkeley Pier.	Northwest wind	8	< .20	< .20
7	Corner Third and Franklin Streets.	West wind; clear	14	< .20	< .20
16	First and Grove Streets	West wind; cloudy	11	< .20	.50
17	Fifth and Market Streets; Twelfth and Chestnut Streets; Twelfth and Bay Streets.	South wind; smoke high	16	< .20	< .20
			148	< .20	1.00

DETERMINATIONS MADE IN RICHMOND AND VICINITY.

The Standard Oil refinery at Point Richmond discharges a large volume of smoke into the atmosphere. Under very light wind conditions this smoke hangs as a cloud over Point Richmond or drifts eastward over Richmond and San Pablo.

Determinations were made at Point Richmond, Richmond, and San Pablo to determine the sulphur dioxide content of the atmosphere. A summary of the data from Point Richmond is given below. The data show that in the direct path of the smoke, within a distance of 1 mile, a comparatively high concentration, as high as 4.5 parts SO_2 per million parts of air was found. It is also to be observed that even when the smoke was not noted as being in the vicinity, the atmosphere contained determinable quantities of sulphur dioxide, averaging 0.40 part SO_2 per million parts of air. In the city of Richmond proper and San Pablo the highest concentration of sulphur dioxide found was 1.8 parts per million parts of air.

Summary of results of tests in Richmond and vicinity.

POINT RICHMOND, SOUTH OR WEST OF STANDARD OIL REFINERY.

Date.	Number of samples.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.
Dec. 6	13	0.30	0.60
Dec. 8	21	1.45	3.60
Dec. 9	20	1.20	3.40
Dec. 15	24	2.00	4.50
Dec. 16	15	.30	2.40
Dec. 18	10	.40	1.00
	103	1.10	.....

The results of the above 103 tests have been segregated as follows: Tests with refinery smoke in vicinity (within 1-mile range); tests with refinery smoke not in the vicinity, or high overhead.

Segregation of results of tests in Richmond and vicinity.

RESULTS OF TESTS WITH REFINERY SMOKE IN VICINITY (WITHIN 1-MILE RANGE).

Date.	Number of samples.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.
Dec. 8	21	1.45	3.60
Dec. 9	15	1.50	3.40
Dec. 15	14	3.20	4.50
Dec. 16	2	1.70	2.40
	52	1.95	.....

RESULTS OF TESTS WITH REFINERY SMOKE NOT IN VICINITY, OR HIGH OVERHEAD.

Date.	Number of samples.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.
Dec. 6	13	0.30	0.60
Dec. 9	5	.20	.30
Dec. 15	10	1.00	1.40
Dec. 16	13	<.20	.40
Dec. 18	10	.40	1.00
	51	.40	.....

RESULTS OF TESTS AT RICHMOND AND SAN PABLO, IN LINE OF SMOKE.

Date.	Number of samples.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.
Dec. 17	19	0.60	[a] 1.80
Dec. 22	14	1.20	[b] 1.80

[a] Three-fourths of a mile to 2 miles from plant.
[b] One to 2 miles from plant.

DETERMINATIONS MADE IN MARTINEZ OR VICINITY, IN THE SMOKE ZONE OF THE MOUNTAIN COPPER CO.'S PLANT.

The Mountain Copper Co.'s plant at Rococo, near Martinez, is situated very favorably for operation without maintaining a smoke nuisance. The plant is located at Suisun Point on Suisun Bay, about 1 mile northeast of Martinez. The smokestack is built on a hill and the smoke is discharged at a considerable height above the surrounding country. During the season of the trade winds, the smoke is generally blown over the tule lands or Suisun Bay to the east or northeast. Only during an occasional north or northeast wind is the smoke from this smelter blown toward Martinez.

In order to determine the concentration of the sulphur dioxide in the air around Martinez and the vicinity, 168 tests were made on 12 days during the investigation periods of the commission. A summary of the data so obtained is given below.

The highest concentration found was only 1.7 parts SO_2 per million parts of air. This was found at a point 1½ miles south of the smelter at a time when the smoke was observed by sight to be in the immediate vicinity. At no time was the SO_2 in the smoke of the Mountain Copper Co.'s plant detected by smell by any of the field men.

The data obtained in this smoke district have been segregated below into three heads, as follows:

(*a*) Determinations made in the smoke stream from the Mountain Copper Co.'s plant.

(*b*) Determinations made when the smoke was blown high overhead at sampling point.

(*c*) Determinations made when the smoke was blown in general direction toward the sampling point.

General summary of results of determinations made at Martinez and Avon—In the smoke zone of the Mountain Copper Co.'s plant.

[Total number of tests, 168; average number of parts of SO_2 per million parts of air, 0.23; maximum number of parts of SO_2 per million parts of air, 1.70.]

Point of sampling.	Number of samples.	Parts of SO_2 per million parts of air.	
		Average.	Maximum.
In smoke stream	10	0.85	1.70
Under smoke stream	121	.20	1.20
In direction of smoke stream	37	< .20	.50
	168	.....	.....

General summary of results of determinations made at Martinez and Avon—In the smoke zone of the Mountain Copper Co.'s plant—Continued.

Limits of concentration (parts of SO_2 per million parts of air).	Number of samples.	Proportion of total.
		Per cent.
0.0 to 0.2	120	71.3
.2 to .4	17	10.2
.4 to .6	11	6.5
.6 to .8	10	6.0
.8 to 1.0	6	3.6
1.0 to 1.5	3	1.8
1.5 to 2.0	1	0.6
	168	.....

Detailed results of determinations made at Martinez and Avon—In the smoke zone of the Mountain Copper Co.'s plant.

IN SMOKE STREAM.

Date.	Place.	Distance from smelter.	Wind.	Number of samples.	Parts of SO_2 per million parts of air.	
					Average.	Maximum.
1913.						
Sept. 23	Martinez	1½ miles south	North	5	1.10	1.70
Nov. 2	Railroad Station	1 mile southwest	Northeast	2	.90	.90
1914.						
Apr. 29	Bulls Head Point	1 mile east	West	3	.40	.50
				10	.....	.....

UNDER SMOKE STREAM.

1913.						
Sept. 23	Martinez	1½ miles south	North	7	0.80	1.20
Oct. 1	Do	do	do	7	.25	.45
Oct. 11	Do	1½ to 2½ miles south	do	15	<.20	.20
Nov. 12	Martinez Station	1 mile southwest	Northeast	13	.30	.40
Nov. 13	Martinez Ball Park	Southwest	do	18	<.20	.40
1914.						
Apr. 18	Martinez between station and Concord Road.	1 to 2 miles south	do	15	<.20	.50
Apr. 29	On Martinez-Concord Road.	1 to 3 miles southeast and south.	North and northeast.	13	<.20	.50
May 6	Avon	3 miles east	West	21	.35	.75
May 7	Peyton	1 mile east	do	12	<.20	1.00
				121	.....	.....

IN DIRECTION OF SMOKE STREAM.

1913.						
Sept. 23	Martinez	1½ miles south	West	2	<0.20	<0.20
1914.						
May 5	Road to Concord	4 to 5 miles southeast	do	6	< .20	.20
May 6	Avon	3 miles east	Northwest	4	< .20	.20
May 7	Bay Point	5 miles east	Southwest	9	< .20	.20
May 8	Sante Fe track south of Avon.	3½ miles southeast	West	16	< .20	.20
				37	.....	.....

TOTAL-SULPHUR DETERMINATIONS OUTSIDE THE SELBY SMOKE ZONE.

The determinations of total sulphur content of the air in places outside the Selby smoke zone were made in the same manner and with the same apparatus as those made in the Selby district. As in the discussion of the sulphur dioxide determinations from "instantaneous" samples, the results will be discussed under the five divisions, as indicated below:

TOTAL-SULPHUR DETERMINATIONS MADE ON OCEAN BEACH IN SAN FRANCISCO.

Due to the fact that in the first set of absorption tubes used, there was some rubber exposed to the action of the bromine and ammonical vapors the solutions were "salted" slightly by sulphur dissolved from the rubber. Thus the first series of total sulphur samples taken in San Francisco were not considered reliable and were discarded. On September 13, 1913, two short total-sulphur determinations were made on the beach, which gave practically a zero value, and the apparatus was then considered free from any internal source of sulphur which could "salt" the samples.

RESULTS OF OTHER TOTAL-SULPHUR DETERMINATIONS.

The results of total-sulphur determinations are presented in the tabulation following:

Results of certain total-sulphur determinations made outside the Selby smoke zone.

DETERMINATIONS IN SAN FRANCISCO.

Date.	Place.	Volume of sample.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average number of parts of SO_2 per million parts of air, "instantaneous" samples.
1913.		*Cubic feet.*		
Sept. 15	Corner Harrison and Sixteenth Streets	6.8	0.90	0.60
Sept. 15	Top of Eighteenth Street hill	5.8	.17	< .20
1914.				
Feb 11	Various points	12.2	.55	.30
Mar. 4	Seventeenth and Mississippi Streets	14.0	.17	< .25
Mar. 5, Mar. 6	Tenth and San Bruno, near Stauffer Chemical Co	30.6	.18	< .25
Mar. 7	Seventh and Berry Streets	20.2	.32	.25
	Average of 6 samples	.....	.38	.....

Results of certain total-sulphur determinations made outside the Selby smoke zone—Con.

DETERMINATIONS IN OAKLAND AND BERKELEY.

Date.	Place.	Volume of sample.	Total sulphur calculated to parts of SO_2 per million parts of air.	Average number of parts of SO_2 per million parts of air, "instantaneous" samples.
1914		*Cubic feet.*		
Jan. 3	Linden and Third Streets	14.1	0.38	<0.20
Feb. 1	Foot of Broadway	16.0	.19	< .20
Feb. 3	Near Southern Pacific roundhouse	16.2	.25	< .20
Feb. 4	Third and Clay Streets	18.1	.19	.20
Feb. 5	Harrison and Third Streets	18.1	.21	< .20
Feb. 6	West Berkeley	12.0	.11	< .20
Feb. 7	Third and Franklin Streets	18.2	.28	< .20
	Average	.....	.25	.....

DETERMINATIONS IN RICHMOND AND VICINITY.

1913				
Dec. 6	West of Standard Oil Refinery	11.0	0.70	0.30
Dec. 8	.....do	14.0	2.60	1.45
Dec. 15	.....do	14.0	2.20	2.00
Dec. 16	.....do	14.0	.55	.30
Dec. 22	.....do	12.0	2.60	1.20
	Average	.....	1.73	.....

DETERMINATIONS AT MARTINEZ [a] AND AVON, IN THE SMOKE ZONE OF THE MOUNTAIN COPPER CO.'S PLANT.

1913				
Oct 1	Martinez, 2 miles south of smelter	14.2	0.56	0.25
Nov. 12	Martinez railroad station	12.8	.90	.40
Nov. 13	.....do	14.6	.62	.40
1914				
Apr. 29	Various points	8.8	.35	< .25
May 6	Avon	12.5	.20	< .25
May 7	Peyton	14.2	.20	< .25
	Average of 6 samples	.....	.41	.....

[a] There was a wide difference between total SO_2 and average SO_2 determinations in Martinez.

COMPARATIVE RESULTS OF SO_2 DETERMINATIONS FROM "INSTANTANEOUS" SAMPLES.

As the tests for sulphur dioxide in San Francisco, Oakland, Richmond, and Martinez were not made under as wide a range of wind and other conditions as were the tests made in the Selby smoke zone, it is not strictly proper to compare the average concentrations found. However, the comparison of the maximum concentrations found may be of some value.

Comparative results of SO_2 determinations from "instantaneous" samples.

Location.	Parts of SO_2 per million parts of air.	
	Average.	Maximum.
San Francisco business section	0.29	1.80
Oakland	<.20	1.00
Point Richmond:		
In oil-refinery smoke	1.10	4.50
Outside refinery smoke	.40	1.80
Richmond city—In oil-refinery smoke	.90	1.80
Martinez	.23	1.70
Selby smoke zone:		
Benicia city	.20	2.40
Agricultural district	.24	7.10

Not many attempts have been made to determine the sulphur dioxide content of the air during a very short interval of time. The only other work that has been done along similar lines, the results of which have been published, is the work of Atherton Seidell and Philip W. Meserve. Their work was to determine the gaseous impurities in the air of railway tunnels, and is described in Bulletin 92, Hygienic Laboratory, United States Public Health Service.

In the Fulton Tunnel of the Pennsylvania Railroad, Baltimore, they found sulphur dioxide concentration varying between 0.2 part and 15.1 parts per million parts of air, with an average concentration of 5.1 parts. In the electrified tunnel of the Baltimore & Ohio Railroad, in the same city, the concentrations found varied between 0.3 part and 2.3 parts.

Comparative results of total-sulphur determinations.

Location.	Total sulphur calculated to parts of SO_2 per million parts of air.	
	Average.	Maximum.
San Francisco business section	0.38	0.90
Oakland	.23	.38
Richmond	1.73	2.00
Martinez, in smoke of Mountain Copper Co	.47	.90
Selby smoke zone, Benicia city limits	.25	1.00
Agricultural area along the Vallejo-Benicia highway	.22	.40
Agricultural area close to straits	.29	1.50

TOTAL-SULPHUR DETERMINATIONS OF OTHERS.

As most of the work that has been done in the past to determine concentration of sulphur dioxide in the air was with a method similar to that used by this commission in determining the average total sulphur dioxide content of the air, it will be interesting to compare some of the results obtained. It must be remembered, however, that such comparisons are of little value in drawing conclusions concerning the relative smoke "nuisance" in the several places.

Baskerville [a] gave the SO_2 contents of the air in New York City:

Results of SO_2 determinations in air of New York City.

Place of sampling.	Parts of SO_2 per million parts of air.
Near a high stack in elevated part of the city	3.14
Various parks, maximum	.84
Railroad tunnels	8.54 to 31.50
Downtown district	1.05 to 5.60
Localities near a railroad	1.12 to 8.40

TESTS TO DETERMINE THE SENSIBILITY OF MAN TO SULPHUR DIOXIDE AT HIGH DILUTIONS.

One of the chief complaints against the Selby smelter by the residents of Solano County has been, and to some extent still is, that the Selby smoke, as it is blown or drifted over the smoke zone, was so offensive to the senses of smell and sight as to be a nuisance and a detriment to health. The smoke is alleged to produce disagreeable symptoms, such as difficult breathing, suffocation, coughing, choking, and even nausea. However, from the preceding data concerning the sulphur dioxide content of the air as determined by analysis at times when the claim was made that the smelter smoke was "smelled" by some of the complainants, it is evident that there was no definite relation between the concentrations of the sulphur dioxide gas and the complaints. Most of the complaints in Benicia were made at times when our field men found only the slightest traces of sulphur dioxide. The complaints from the people at Glen Cove or around the White Ranch were made at times when the highest concentrations were found.

None of our field men suffered any severe or especially disagreeable symptoms on the few occasions that the sulphur dioxide was smelled by them. The most disagreeable sensation was the irritation in the throat and slight tendency to cough.

Thus, in order to determine whether the concentrations found by field tests in Benicia could be responsible for the nuisance claimed, it was very essential for the commission to make an extensive series of tests, with many persons as subjects, to determine the effects produced by breathing known concentrations of sulphur dioxide.

As a first step in this endeavor it was necessary to determine the minimum concentration, or in other words, the maximum dilution, at which the sulphur dioxide may be detected by the sense of smell or taste or by any symptoms produced. By increasing the concentration above that point the effect of the sulphur dioxide on many people was studied up to a concentration at which the sulphur

[a] Baskerville, Charles, The smoke problem and the community: Jour. Ind. and Eng. Chem., vol. 2, August, 1910, p. 359.

dioxide was declared a positive nuisance. In the case of a few subjects the concentration was carried much higher, in fact, up to a concentration at which it was difficult to breathe the gas for more than a few seconds. These investigations were conducted in one of the rooms of the United States Bureau of Mines at the San Francisco customhouse. The apparatus and the method used for getting the known mixtures of sulphur dioxide and air were the same as used in the tests to determine the accuracy of the analytical methods. As described fully in the discussion of those tests, the method consisted of adding continuously a metered volume of sulphur dioxide to a known volume of air, which mixture was driven by a blower through a mixing box and pipes into a booth, in which a person could stand or sit in a normal position. Plate X, *B*, shows the arrangement of meter, fan, mixing box, and booth.

In the first determinations of this character the subject whose sensibility to sulphur dioxide was being determined was required to breathe the mixture as it was blown through a "smelling box" 12 inches square and 18 inches long, open at the end, before which the subject stood. Due to the fact that the subject was more or less influenced by the rush of air at quite high velocity into the face, it was thought advisable to have the subject sit or stand in a booth where, the air being comparatively quiet, the subject would be in a more passive state and less likely to be influenced by the imagination. Being in the booth and not allowed to see what changes were made by the operator, the subject was able to detect the changes only by the effect on himself, which served partly to eliminate the factor of imagination. In order to eliminate still further the factor of imagination, several tests were made while the subject, by reading or writing in the booth, tried to divert his attention to other things. The effects of the different concentrations were noted by the subject only when requested by the operator.

In order to determine the concentration at which the sulphur dioxide could first be recognized, the tests were carried out in a variety of ways. In most cases the concentration of sulphur dioxide in the air surrounding the subject was gradually increased from zero to any desired amount, the subject stating when the presence of the gas was suspected and when it was positively identified. As the concentration was gradually increased above the identification point, the effect of the gas on the subject was noted. In other cases the subject was brought directly from comparatively pure air outside the room into the booth containing a definite concentration of sulphur dioxide and the effects noted. Several tests were made in which the subject was surrounded by an atmosphere containing sulphur dioxide above

the detection point, and then either abruptly or gradually the concentration was decreased until the subject stated that the gas was not detected.

As a general rule, when a person went directly from a sulphur dioxide free atmosphere into one containing a mixture, the sulphur dioxide was identified at a slightly lower concentration than if the concentration had been raised gradually. For example, many subjects who could identify a faint trace of sulphur dioxide at 3.5 parts per 1,000,000 when the concentration was gradually raised to that degree could detect the gas at 3 parts when the concentration was raised abruptly from zero.

If the concentration was raised gradually to the point at which it just could be identified, and remained constant at that concentration, there arose a doubt in the minds of many subjects after a few minutes as to whether or not the sulphur dioxide was present, and only by having the concentration raised slightly could these subjects detect it again. Following this feature still further, it was found that if a subject was allowed to breathe a concentration above the point at which the sulphur dioxide was just plainly smelled, and the concentration was then decreased very gradually, the point at which the disappearance of the sulphur dioxide smell was noted was somewhat higher than the point at which its presence was first noted. On the other hand, if the sulphur dioxide was cut down rather abruptly from the above point, the smell or taste of the sulphur dioxide persisted in many cases even after the concentration was lower than the point at which the first smell was noted. This persistency of smell or taste was especially noticeable when the subject had been given a rather strong dose. In the following table the data given are those obtained by gradually increasing the sulphur dioxide concentration in the air breathed by the subject while seated or standing in the booth.

The total number of persons who were kind enough to aid in the tests was 60. As many of these subjects were tested several times, the total number of recorded tests was about 85. Of the 60 subjects, 32 were previously rather well acquainted with the smell of sulphur dioxide, being chemists, engineers, or men who at some time had had some experience with that gas. The remaining 28 were not well acquainted with the gas. This class of subjects included janitors, carpenters, insurance agents, clerks, stenographers, etc. Although it was not possible to classify all the subjects accurately under the two heads, in regard to their being or not being acquainted with the smell of sulphur dioxide, an attempt has been made in the two following tables to approximate that classification.

Results of tests of effects of SO_2 on persons.

PERSONS PREVIOUSLY ACQUAINTED WITH SULPHUR DIOXIDE SMELL.

Parts of SO_2 per million parts of air.	Effect on persons.			
	Did not detect SO_2.	Doubtful as to smell.	Faint smell or taste.	Plainly identified gas as SO_2.
1	32	.....	.....	.....
2	19	11	2	.....
3	6	5	13	8
4	2	3	6	21
5	1	.....	5	26
6	1	.....	2	29
8	1	.....	.....	31
10	1	.....	.....	31
12	.....	1	.....	31
16	.....	.....	1	31
20	.....	.....	.....	32

PERSONS NOT WELL ACQUAINTED WITH SULPHUR DIOXIDE SMELL.

1	28	.....	.....	.....
2	26	[a] 2	.....	.....
3	18	[a] 4	.....	6
4	14	[a] 4	.....	10
5	6	[a] 10	.....	12
6	2	[a] 6	.....	20
8	.....	[a] 2	.....	26
10	.....	[a] 1	.....	27
12	.....	.....	.....	28

[a] Did, however, detect faint smell or taste of something foreign.

Referring to the tabulation of the results obtained from those subjects who knew previously the smell of sulphur dioxide, it will be noted that no one could detect 1 part per million. In atmosphere containing 2 parts per million, 13 of the 32 (40 per cent) suspected the presence of something foreign in the air; 2 of them by sense of taste thought they recognized a faint trace of sulphur dioxide. With 3 parts per million, 26 of the 32 (80 per cent) realized the presence of an acid gas, 5 being doubtful as to its being sulphur dioxide, 13 detecting a faint trace, and 8 identifying it plainly as sulphur dioxide. At 4 parts per million, only 2 subjects were unable to detect the presence of an acid gas, these 2 being men who had spent much time in smelter-furnace gases and thus had become so accustomed to the sulphur dioxide gas as to be insensitive to it. Twenty-one identified it plainly as sulphur dioxide. At 5 parts per million, practically all subjects smelled the gas either plainly or faintly.

Referring to the results of tests on those not so well acquainted with the smell of sulphur dioxide, it is to be noted again that none detected 1 part per million, and only 2 detected any foreign smell at 2 parts of sulphur dioxide per million parts of air. With a concentration of 3 parts per million, 6 subjects identified sulphur dioxide as being "burning sulphur," and 4 "smelled something." It was not until the concentration was raised to 5 parts per million that the

greater proportion of this class of subjects detected the presence of a foreign odor, and at 6 or 7 parts per million practically all had identified the odor, upon suggestion, as that of "burning sulphur." Having familiarized this class of subjects with the smell of sulphur dioxide, on a second test they were found to be about as sensitive as the first class.

It was concluded that the average person, who knew the smell or taste of sulphur dioxide, could detect its presence in the atmosphere when the concentration was between 3 and 3.5 parts per million. The average person not well acquainted with the smell could detect the presence of sulphur dioxide when the concentration was between 4 and 5 parts per million.

The manner in which the sulphur dioxide was identified differed with different subjects. Some identified the gas by the taste and some by the smell. In only a few cases was any throat irritation caused by a concentration of less than 5 parts per million. In breathing a mixture of over 5 parts per million, however, the action of the sulphur dioxide on the throat was more and more apparent, and at 10 parts per million was sufficiently irritating to cause most subjects to feel slight discomfort and to cough. As the concentration was further increased the tendency to cough became more marked, and its action on the eyes produced watering of the eye.

The concentration that produced irritation, coughing, and eye watering varied greatly with the individual and the length of time during which the concentrations were maintained. Thus, the concentration that the average person would call a nuisance was difficult to determine. Not only were the varied susceptibilities and the time factor to be considered, but what was even more of a factor in determining the nuisance question was the mental attitude of the individual in regard to the smell. If one was inclined to call a slight smell of a foreign gas in the atmosphere a nuisance, then a concentration of from 3 to 4 parts per million would be a nuisance. If, however, one did not consider it a nuisance until the concentration was sufficiently high to cause disagreeable throat irritation or coughing, the nuisance point would be very much higher. For example, one of the chemists for the commission considered it a nuisance to breathe for even a few minutes more than 3 parts sulphur dioxide per million, the concentration just above that at which he could detect the gas. Another chemist for the commission could detect the sulphur dioxide at the same concentration (3 parts per million) but breathed an atmosphere of 20 parts for a considerable period of time without calling it a nuisance.

The psychological element influencing these figures was illustrated further in the fact that many subjects called a certain concentration

a nuisance on one day and on another day breathed a higher concentration for a much longer period of time without stating that it was disagreeable. The time factor, of course, is very great in determining what concentrations are nuisances. What one could readily breathe for periods of several minutes at intervals, without any disagreeable features, was an actual discomfort after a longer period of steady duration.

Thus, the conclusions arrived at by these tests to determine the concentration that may be considered a nuisance are very general.

With the exception of a few cases, no subjects thought that any concentration less than 5 parts sulphur dioxide per million, even if continued for a considerable length of time, could be considered a nuisance. Occasional short period whiffs of less than 5 parts per million certainly could not be considered a nuisance to anyone. Long-continued breathing of air containing slightly more than 5 parts per million would probably cause discomfort to most people, though occasional momentary whiffs of 5 to 10 parts per million would not be disagreeable. As a few breaths of a mixture containing more than 10 parts sulphur dioxide per million caused the greater proportion of the subjects to feel the throat irritation and coughing, such a concentration, even if present at long intervals, and for only a very short time would probably be called a nuisance by most people.

In order to study the effect of concentrations stronger than 20 parts sulphur dioxide per million a special series of tests were made with several interested chemists as subjects. At 20 parts the concentration was declared very disagreeable, causing very distinct throat irritation and after a few breaths caused a heavy feeling in the chest. As the concentration was raised to 50 parts the action of the gas on the eyes became more pronounced, the throat and chest irritation becoming more acute. However, it was possible for a person to breathe that concentration for several minutes. Concentrations as high as 150 parts sulphur dioxide could be breathed by several men for a period of several minutes, although the sensations produced were extremely disagreeable. When the concentration was raised to 500 parts per million the gas was so acutely pungent as to cause the sensation of suffocation, even with the first breath.

Thus, sulphur dioxide at great dilution can be recognized in one of the following ways: Acid taste; sharp, pungent odor; at higher concentration by irritation of throat membrane, causing coughing; irritation of eyes, causing watering; at still higher concentration, by acute irritation of eyes or throat, and by producing a sense of suffocation.

With no concentration of less than 50 parts per million was there produced any feeling of nausea, and the tendency to nausea with the highest concentrations was only slight.

The data obtained in these tests check very closely the data obtained by Lehmann.[a] These earlier data show that in an atmosphere containing 6.5 to 11.5 parts per million there was only moderate discomfort, as stinging of the nose, after 10 or 15 minutes. With 14 or 15 parts there was considerable discomfort, which could be borne for ½-hour periods. In an atmosphere containing 30 parts per million the conditions were almost unbearable.

RELATION OF THE HAZY AND SMOKY CONDITIONS SOMETIMES PRESENT IN THE SELBY "SMOKE ZONE" TO THE SMOKE FROM THE SELBY SMELTER.

Before the installation of the bag house for the sintering-machine gases, the Selby plant contributed visible smoke to the atmosphere. Under very light west wind conditions this smoke was visible over Glen Cove, Dillon Point, and even as far east as Benicia. At Glen Cove and Dillon Point the smoke was at times rather dense. From a distance it could be seen clearly, but only when it was especially dense was it noticeable close at hand.

At Benicia the smoke was never dense. Looking across the straits to Benicia from Porta Costa, the Selby smoke could be seen, occasionally, as a faint haze drifting over the town. Only on two or three occasions was it possible to tell that the smoke was present when the observer himself stood in the path of the smoke.

During the months of September and October, 1913, there were many days when the air all around Vallejo and Benicia was hazy and smoky. However, it was evident by a little study of the conditions that the Selby smoke was only a very small part of the total general haze.

On August 24, 1913, Mr. Dutton and the writer noted that the air in the vicinity of Vallejo and Benicia was very hazy and smoky, as was the case all over the adjacent country. They noted that the smoke from the Selby smelter on that day was only a very thin stream and was drifting in a southeasterly direction from the smelter over the Contra Costa hills.

The general haze noted on September 17, 1913, was dense all over the bay district, and was no worse in the Selby "smoke zone" than elsewhere.

On October 20, 1913, at 2.30 p. m. the wind which had been blowing from the north changed into the west, and a very dense bank of smoke came drifting along the straits clinging to the north side. A special trip was made by the writer to a point where the smelter smoke stack could be seen, and it was evident that the smoke from the single sintering machine then in operation at the smelter was only a

[a] Lehmann, K. B., Experimentelle Studien über den Einfluss technisch und hygienisch wichtiger Gase und Dämpfe auf den Organismus. Archiv Hygiene, vol. 18, 1893, pp. 180-191.

very small portion of the dense bank of smoke. The greater portion appeared to come up along the east shore of San Pablo Bay. Samples were taken in the direct path of this smoke bank as it drifted into Benicia, which gave a concentration as high as 1.6 parts SO_2 per million and showed that the smelter smoke was a part of the smoke bank. Although this smoke bank was dense when viewed against the background of some hills, when the observer was directly in the path of the smoke it was not very perceptible.

On several days during the spring months of 1914, after the installation of the bag house which eliminated the posibility of the Selby plant contributing to the visible smoke, the smoky and hazy appearance of the air in the Selby "smoke zone" was still noted.

In this connection it may be well to bear in mind the fact that the Union oil refinery at Oleum and the Standard Oil refinery at Richmond discharge, at times, very dense smoke into the air. From analyses made in the vicinity of Richmond, it was found that the smoke from the Standard Oil refinery contained relatively high amounts of sulphur dioxide. If some of this smoke which drifted up the straits to Benicia on October 20, 1913, contained the smoke from the Standard Oil Co. or Union Oil Co., it is barely possible that some of the sulphur dioxide found in the atmosphere of Benicia at that time was due to the oil refineries.

At no other time, however, was there an indication of appreciable quantities of sulphur dioxide coming to Benicia from the oil refineries.

SUMMARY CONCERNING CONTAMINATION OF ATMOSPHERE IN SELBY "SMOKE ZONE" BY SULPHUR DIOXIDE FROM THE SELBY SMELTER, AND CONCLUSIONS AS TO WHETHER THIS CONTAMINATION CONSTITUTES A SOURCE OF NUISANCE TO PEOPLE RESIDING IN THE "SMOKE ZONE."

GENERAL CONDITIONS.

1. When the wind was from the west and blew the smoke from the Selby smelter over the areas referred to in this report as the "smoke zone," there was present in the air of this area a higher concentration of sulphur dioxide than was found when the wind was blowing from other directions. This concentration is higher than is normally present in the atmosphere outside of large cities.

2. Although at times there may have been appreciable contributions to this contamination from sources situated southwest or west of Selby, little evidence of sulphur dioxide from other sources was found during these investigations. The sulphur dioxide contamination was due mainly to the emanations from the Selby smelter. Only when the wind was blowing the smoke directly from the smelter over the area were the higher concentrations found.

3. The concentration of sulphur dioxide in the air was not entirely proportional to the sulphur dioxide output from the Selby smelter, for the concentration at any point was influenced to a great extent by the atmospheric conditions.

4. No indications were found of the presence of very high concentrations during the early morning hours. The highest concentrations were found in the samples taken about noon or in the early afternoon.

5. Under moderate or brisk wind conditions, the increase in sulphur dioxide concentration was not very great in any part of the "zone," a maximum of 1.25 parts of SO_2 per million parts of air being found when the smelter was sending out sulphur dioxide at the rate of 70 tons per day.

6. Under a very slight west or southwest wind or a drift of air from the smelter across the "smoke zone" the concentration at certain places became relatively rather high for short periods of time. These high concentrations were found only when there were puffs of smoke relatively undispersed or poorly dissipated drifting past the point of sampling.

7. These puffs of Selby smoke were not of long duration at any time and came only at infrequent intervals. They were present more often and with higher sulphur dioxide content over the land lying nearest the straits and west of Dillon Point than in the city limits of Benicia or over the agricultural area bordering along the Vallejo-Benicia highway. For that reason it is desirable to consider the conditions in the farming area close to the straits separate from the rest of the "zone."

SMOKE CONDITIONS IN BENICIA CITY LIMITS.

At no time during the period of field investigations of this commission has the smoke from the Selby smelter been present in the city of Benicia to such an extent as to constitute a nuisance.

This is fully established by the following facts:

Even under the worst wind conditions and with an output from the Selby plant varying up to a maximum of 90 tons of sulphur dioxide per day, the maximum concentration found in the city of Benicia was only 2.40 parts of SO_2 per million parts of air.

Whenever the concentration was above 1 part of SO_2 per million parts of air, which was found in 22 samples out of 2,841 (0.8 per cent) it was due to puffs of poorly dispersed or diffused smoke drifting into the city. The concentration was not observed to remain above that figure for more than a maximum period of 20 minutes at any one time. It may be possible that slightly higher concentrations were present momentarily when observers were not in the field.

The maximum concentration found in Benicia was only slightly greater than that found in the downtown section of San Francisco

on smoky mornings during September, 1913. Higher concentrations have been found in the smoke zone of the Standard Oil refinery at Point Richmond.

The tests to determine the sensibility of human beings to sulphur dioxide showed that the average person required to be surrounded by an atmosphere containing at least 3 parts of SO_2 per million parts of air before he could detect the presence of the gas either by smell or taste. The average person did not consider concentrations of 5 or 6 parts of SO_2 per million parts of air, lasting for several minutes, a nuisance. Assuming that there are many people in Benicia who are especially susceptible to the gas, and can smell concentrations as low as 2 parts of SO_2 per million parts of air, there was only one recorded instance of the concentration being sufficiently high for those people to smell the gas. It is possible that at one or more points there may have been concentrations about as high as 2.4 parts per million for brief periods, but as less than 1 per cent of the examinations made show concentrations higher than 1 part SO_2 per million, this is improbable.

If complaints had been made by the citizens to our field men at times when the maximum concentrations had been found by analysis it would be easier to believe that the people of Benicia were consistently highly susceptible to the effects of sulphur dioxide. However, as was shown above, complaints were made at times when only very low amounts of sulphur dioxide were present—amounts entirely too small to be smelled by the most sensitive. In fact some of the most insistent complaints were made at times when the wind was from a direction other than the west and it was not possible for the Selby smoke to be in the vicinity, and the sulphur dioxide, if present, was below the quantity we could determine—that is, 0.2 part SO_2 per million. Our field men smelled the smoke in Benicia only on two occasions and then for only a brief period and only slightly.

In view of the fact that determinations, made under all kinds of wind conditions, and with variable amounts of sulphur dioxide emanating from the Selby smelter, showed that there was very seldom in the air a concentration sufficiently high for even an especially susceptible person to detect the sulphur dioxide, and in view of the fact that the people of Benicia complained frequently of the smoke when it was not possible for the smoke to be in the vicinity, it is impossible to believe that the Selby smoke has constituted a nuisance at any time in the city of Benicia during this period. Further, it is reasonable to conclude that with an output as high as 100 tons sulphur dioxide per day from the Selby smelter there is little possibility of this sulphur dioxide causing a nuisance to the people residing in Benicia, although the smoke may be detected occasionally by smell for a brief period.

It should be noted that with concentrations up to 20 parts SO_2 per million, none of the subjects experimented upon experienced a feeling of nausea or any symptom other than an irritation of the throat and a tendency to cough. Thus it is evident that the symptoms of nausea, the smelling of "rotten eggs," "dead cats," or the "suffocating odor" as described by the people of Benicia can not be due to the smell of concentrations of sulphur dioxide gas that are present at rare intervals in the city, or in any part of the "smoke zone."

SMOKE CONDITIONS IN THE AGRICULTURAL DISTRICT.

The part of the agricultural district immediately bordering the shore of the straits, west of Southampton Bay, was the only part of the "smoke zone" that received the smoke in sufficient strength to permit the possibility of the sulphur dioxide being a nuisance. Back of the range of hills directly north of the straits the smoke was seldom present. Only on one day in this part of the "smoke zone" were samples taken that contained more than 1 part SO_2 per million. The smoke was never smelled by our field men in the part of the "smoke zone" back of the above-mentioned line of hills. However, here, as in other portions of the "smoke zone," the oil fumes were frequently smelled.

At times the smoke drifted into Elliott Cove and Glen Cove and along the hills east of Glen Cove, past station 2 on the White ranch, in sufficient strength for the sulphur dioxide to be detected by smell. As shown by the data given above, there were 16 days during the period of investigation when the smoke was observed by eye passing the station, and on 4 days (3 per cent of the days on which observations were taken) the sulphur dioxide was detected by smell. On one of these days the smoke was strong enough to be a possible nuisance for two periods totaling 35 minutes. On this day, under the worst possible wind conditions and with an output from the Selby plant as high as 80 tons of sulphur dioxide per 24 hours, the concentration was found to be 7.1 parts of SO_2 per million parts of air. This was the highest concentration ever found in the "smoke zone." This concentration, continued for several minutes, is sufficiently high to cause people sensitive to sulphur dioxide to feel an irritation of the throat and a tendency to cough. However, out of the 60 different people tested to determine their susceptibility to sulphur dioxide there were only two or three who considered short periods whiffs of concentrations of 5 to 10 parts per million as a nuisance.

If it be assumed that people especially sensitive to sulphur dioxide were at this station during the period of 117 days when samples were being taken there, they might have smelled the smoke on 7 days, or on 11 different occasions, for a maximum period at any time of about 25

minutes. If it be assumed that people with only average sensibility were present, then only on 4 days could the smoke have been smelled.

It must be conceded that in the vicinity of the White farmhouse, or Glen Cove and Elliott Cove, that there is a possibility of the sulphur dioxide from the smelter being in sufficient strength at times to be detected by the average person and to especially supersensitive persons to be a nuisance. However, these periods when the sulphur dioxide is present in these strengths are only few and far between during any season, and with the Selby output restricted to not over 100 tons sulphur dioxide per day should not be considered sufficient cause for a nuisance complaint.

CONCLUSIONS CONCERNING THE POSSIBILITY OF SULPHUR DIOXIDE FROM THE SELBY PLANT BEING A MENACE TO AGRICULTURAL PURSUITS IN THE "SMOKE ZONE."

With an output from the Selby smelter of less than 100 tons sulphur dioxide per day, the possibility of the gas being sufficiently strong and present often enough to do material damage to the vegetation growing in the "smoke zone" is very remote. However, it was shown in our fumigation experiments on growing barley[a] that any concentration of sulphur dioxide if applied for a sufficiently long time or in a sufficient number of short-time fumigations would do damage.

If the concentration of sulphur dioxide found during a total of 35 minutes at White's place on October 28, 1913, was present over a grain field during the growing season—that is, between February and early May—it is very probable that visible bleaching would have been produced. With this exception, however, it is safe to state that at no other place where the tests were made, nor at any other time, was the gas present in sufficient strength for a short time, or present in smaller concentrations for a sufficient number of repeated longer time fumigations to produce a visible bleach on the grain if applied during the growing season.

From the fumigation experiments it was found that there was no indication of "invisible injury" to grain to decrease the yield of the crop. Any injury sustained was always visible and, under certain conditions, a considerable amount of visible injury did not necessarily mean a decrease in the yield of the crop. Thus it is proper to conclude that as the Selby smoke is not likely to produce visible injury to the vegetation in the zone there is no danger of invisible injury taking place.

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[a] See Fumigation Experiments to Determine the Effect of Highly Diluted Sulphur Dioxide on a Growing Grain Crop, p. 213.

The writer personally conducted some experiments in Utah during this season to determine the relative susceptibility of grain crops and other field plants to sulphur dioxide. As a result it was shown that the grains—barley, oats, and wheat—are especially susceptible to sulphur dioxide as compared with other crops, as, for example, potatoes, corn, and beets. Thus it must be concluded that as the sulphur dioxide from the Selby smelter is not likely to do damage to grain crops in the "smoke zone" the other crops in that district are not in any danger of being damaged.

If the smoke from the Selby smelter was present over the area during the wet winter months as frequently, or in as concentrated a form, as was found on several occasions during the dry season—that is, during the season of the "trade winds"—it is quite possible, even probable, that with the Selby plant turning out sulphur dioxide at the rate of 100 tons per day there would occasionally be some visible injury to vegetation in the area close to Dos Reis, Elliott, and Glen Coves or on the White place. The possibility of such bleaching taking place in other sections of the smoke zone, however, is remote.

Considering the fact that it is not during the wet season that the smoke is present to any extent over the area, and that during the dry season it is present only on infrequent occasions in sufficient strength to do damage, it is right to conclude that the Selby smoke does not constitute a menace to the successful growing of crops in the smoke zone.

DETERMINATION OF THE DEPOSITION OF LEAD AND ARSENIC ON THE SOIL IN THE SELBY SMOKE ZONE.

Inasmuch as the roaster gases from the Selby plant were going out into the air unfiltered prior to April, 1914, and carried most of the lead and arsenic fumes produced in these furnaces, it is reasonable to suppose that there might have been an appreciable deposition of these fumes on the soil of the smoke zone. The tests used to determine the extent of such deposition were qualitative rather than quantitative. For this purpose pairs of glass plates were set up at three points in the district. These plates were 4 by 6 feet in area. One plate of each set was covered with a thin coating of glycerine or vaseline; the other was left clean. The plates were slightly elevated from the ground and set to face the direction of the smelter, at an angle of about 45 degrees from the horizontal.

Set 1 was placed at station 2, on the White ranch. Set 2 was placed near the house of Mr. Miles Carty, near the western end of the town, close to the Benicia-Vallejo road, and almost in a direct line from the smelter behind set 1. Set 3 was placed near the farmhouse on the Dana place, a point almost in the same line as No. 1 and No. 2.

HISTORY OF PLATE SAMPLES.

SET 1.

These plates were set up on October 28, 1913, and one plate was coated with glycerine on that date. On November 3 it was found that the heavy rains of November 1 and 2 had washed the plates clean. On this date one plate was coated with a heavy layer of vaseline. Although many heavy rains during the month of November kept the other dry plate clean and free from dust, at each time the samples were taken there was an appreciable amount of dust on the vaselined plate. The vaselined plate was cleaned and recoated about every five days. The samples were all put together for a composite. The total time that the plate was exposed and catching dust was 30 days during the fall and early winter of 1913. On March 30, 1914, these plates were set up again. A few days after being set up one of the plates was broken by stock running in the field. Thus, no data from the dry plate were obtained from this set. The other plate was kept covered with a thin coat of vaseline from April 1 to May 13, samples being taken from time to time by rubbing off this thin coat on strips of cotton cloth. The samples taken in April, when the roaster bag house at Selby was in operation, were put together. The two samples taken between May 1 and 13 were analyzed separately to determine the precipitation during the time when the plant was operating three sintering machines and a Ropp roaster, and the bag house was not being used.

The samples of set 1 were taken as follows: No. 1, November 3 to December 3, 1913, 30 days. No. 1*a*, April 1 to May 1, 1914, 30 days. No. 1*b*, May 1 to May 13, 1914, 13 days.

SET 2.

These plates were set up on October 28, 1913. The rains of November 1 and 2 washed both plates so that on November 3 there was nothing on them. One plate was coated then with a heavy layer of vaseline. The deposit on this plate was removed and the plate recoated on November 10, 13, 20, and 28, and December 3. On November 10 and 20 a slight deposit was found on the dry plate. To remove this deposit, the plate was smeared with vaseline and the vaseline then scraped off. The plates were left out over winter, one plate having a very heavy coating of vaseline. On March 15, 1914, the vaseline and deposit from the winter was removed and the plate given a fresh coat. As at set 1, the vaseline was only lightly smeared over the surface during the spring sampling, but as there was very little precipitation of rain during these months, this thin coating was undoubtedly effective in catching the dust. To remove the sample,

it was necessary to rub off the vaseline with a clean cotton cloth, the cloth being included with the sample in the subsequent analysis. As with the samples from set 1, those taken between March 15 and May 1 were put together into one sample, and the samples taken after May 1 were put onto a second composite sample.

The samples of set 2 were taken as follows: No. 2, November 3 to December 3, 1913, 30 days. No. 2*a*, December 3 to March 15, 1914, 102 days. No. 2*b*, March 15 to May 1, 1914, 46 days. No. 2*c*, May 1 to May 13, 1914, 13 days. No. 4, dry-plate sample.

SET 3.

Although these plates were set up on October 28, it was not until after November 3, when one plate was coated with vaseline, that any dust was collected. Samples were taken, and the plates were recoated on November 12, 20, and 28, and December 4. No good samples were taken from the dry plates, because the rains kept this plate well washed off. Early in the spring months these plates were broken by stock running in the field, and were not replaced.

Sample 3 was taken November 3 to December 4, 1913, 31 days.

DETERMINATION OF LEAD AND ARSENIC IN SAMPLES.

All of the samples containing the large excess of vaseline, namely, samples 1, 2, and 3, and the special sample taken from the dry plate at the Carty place (No. 4) were analyzed by Mr. C. E. Brandt, in the laboratory of Gould, Free & Ash. The samples taken on the cotton cloths, namely, Nos. 1*a*, 1*b*, 2*a*, 2*b*, and 2*c*, were analyzed by Mr. G. C. Bartells in the laboratory of the San Francisco office of the United States Bureau of Mines.

SAMPLES 1, 2, AND 3.

These samples were treated with petroleum ether to dissolve the vaseline. The residual solids were weighed. The solids were then divided, one part being used for the determination of lead and the other for arsenic. The part for the arsenic determination was treated directly in a Marsh apparatus, the resulting reduced arsenic was collected in a hard-glass tube, and the mirror compared with standard mirrors. The part for lead was treated with nitric acid, and then brought to fumes with sulphuric acid, the solution diluted and filtered. The lead sulphate was dissolved in ammonium acetate, and the lead precipitated as lead sulphide. This sulphide was then dissolved in nitric acid and the lead again precipitated as sulphate. After taking the solution to dense acid fumes the solution was diluted and the lead sulphate was filtered and weighed.

Results of analyses of samples 1, 2, 3, and 4 for determination of lead content.

Sample No.	Number of days' deposit.	Total dust.	Lead.	Arsenic.	Parts per million parts of total solids.	
					Lead.	Arsenic.
		Grams.	*Grams.*	*Grams.*		
1	30	0.8932	0.0037	0.0000085	4,150	10
2	30	1.075	.0028	.00004	2,600	37
3	32	1.200	.0010	.00006	800	50
4	[a] 20	.508	.0005	.000003	900	6

[a] Approximate.

Blanks were run on the vaseline. No lead was found, and arsenic was present to the extent of a very slight trace, which would amount to a correction of less than 1 part in 1,000,000, applied to the above results.

It is to be noted that the lead content of this dust is much greater than that found in the soil samples taken for the soil investigation of Mr. E. E. Free and Prof. Charles F. Shaw.

SAMPLES 1*a*, 1*b*, 2*a*, 2*b*, 2*c*.

These samples, consisting of a small amount of vaseline on a strip of cotton cloth, were first treated with nitric and sulphuric acid and the organic matter destroyed. The solutions were then heated to dense white fumes of sulphuric acid. The lead sulphate was then filtered, redissolved, and reprecipitated. The resulting pure lead sulphate was then weighed. No arsenic determinations were made on the samples.

Results of analyses of samples 1a, 1b, 2a, 2b, and 2c.

Sample No.	Number of days' deposit.	Quantity of lead in sample.
		Grams.
1*a*	30	0.0005
1*b*	13	.0022
2*a*	102	.0057
2*b*	46	.0000
2*c*	13	.00025

Comparison of rate of deposition on the dust-catching plates.

ROASTER BAG HOUSE NOT IN OPERATION.

Time.	Place.	Deposition per plate (area, 24 square feet) per day.		
		Total.	Lead.	Arsenic.
		Grams.	*Grams.*	*Grams.*
November, 1913	Set 1, White's	0.0297	0.000123	0.00000028
	Set 2, Carty's	.0359	.000093	.0000013
	Set 3, Dana's	.0375	.000037	.0000020
December, 1913, to March, 1914	Set 2, Carty's	.....	.000056	.....
May 1 to May 13, 1914	Set 1, White's	.....	.000170	.....
	Set 2, Carty's	.....	.000020	.....

ROASTER BAG HOUSE IN OPERATION MOST OF THE TIME.

April, 1914	Set 1, White's	.....	0.000017	.....
	Set 2, Carty's	.....	.000000	.....

SUMMARY OF RESULTS.

During November the rains were so frequent and so heavy that no dust could be obtained from the dry plates. Even from the thickly coated vaseline plates it is probable some of the dust was washed off by the rains. Thus the data from these plates during November were not very satisfactory and were far from being quantitative. However, there is no doubt that lead and arsenic were both deposited on the plates. About the same amount of total dust was collected on the different plates. The proportions of lead and arsenic in this dust varied. The dust collected on the plate at the White ranch contained the maximum lead, 4,150 parts of lead per million parts of total dust. The dust collected at the Carty place carried 2,600 parts per million. The lowest lead content was found in the dust collected at the Dana place, which carried only 800 parts lead per million.

The proportion of arsenic present in the samples was in the reverse order, the sample from the Dana place containing the largest amount, 50 parts per million, and the sample from White's containing only 10 parts. No explanation for this anomaly is evident.

It will be noted also that the total weight of dust collected on the plates was slightly greater at the Dana place than at the Carty, which in turn was greater than that collected at the White place.

During April the roaster bag house at Selby was not in continuous operation, owing to some troubles in operating details. Thus, some lead escaped at times. This fact undoubtedly explains why lead was found in the sample from the White place during that month.

In order that the rate of deposition at the several places and at different times may be readily understood, the comparative rate has been tabulated as shown below.

As the plates were placed at an angle of about 45° from the ground, the deposition was undoubtedly greater than would have been obtained upon horizontal plates. Thus, to base the deposition on the soil from the data of the deposition on these plates would be wrong. However, it is interesting to see what the deposition on the soil would amount to if equal to the deposition on these plates. The calculated deposition on the soil thus obtained is as follows:

Calculated deposition of dust at different places.

ROASTER BAG HOUSE NOT IN OPERATION.

Time.	Place.	Deposition per acre per year.	
		Lead.	Arsenic.
		Grams.	*Grams.*
November, 1913	White's ranch	82	0.2
	Carty's place	62	.8
	Dana's place	21	1.2
December, 1913, to Mar. 15, 1914	Carty's place	37	.....
May 1 to May 15, 1914	White's ranch	113	.....
	Carty's place	13	.....

ROASTER BAG HOUSE IN OPERATION MOST OF TIME.

Apr. 1 to May 1, 1914	White's ranch	10	.....
	Carty's place	0	.....

The addition of 113 grams lead per acre year to the top 2 inches of soil, assuming all the lead to remain there, would increase the lead content of that part of the soil by 0.4 part of lead per million parts of total weight.

In arriving at this figure, 3,500,000 pounds was used as the weight of an acre-foot.[a]

CONCLUSION.

When the roaster smoke was allowed to go out into the atmosphere unfiltered from the Selby plant there was undoubtedly a very slight deposition of lead on the soil of the "smoke zone." However, the amount so deposited was very small and would have required many years' deposition to bring about an appreciable increase in the lead content of the soil.

However, with the successful operation of both the bag houses there is no possibility of further deposition.

[a] Hilgard, E. W., Soils, 1906, p. 107.

DETERMINATION OF LEAD AND ARSENIC PRESENT IN THE GRASSES AND STRAW IN THE SELBY "SMOKE ZONE."

On November 30, 1913, the day before the first rains of the season, five samples of the dried and closely matted grasses were taken in the Selby smoke zone. The samples were taken by Mr. A. E. Wells along the front of the bluffs on the north side of the straits between station 2, at White's ranch, and Dead Mans Point. The grasses were dry and dusty, as no rain had fallen on them since early in the preceding summer. Thus they would contain the maximum amount of lead and arsenic that might be deposited from the smelter smoke. These samples were all united to make one composite sample.

The total weight of the samples was 354 grams. Five grams was used for the determination of arsenic. Two hundred and fifty-four grams was used for the lead determination. These determinations were made by Mr. C. E. Brandt in the laboratories of Gould, Free & Ash.

METHOD OF DETERMINING LEAD.

The sample, 254 grams, was digested with HNO_3 until decomposed, sulphuric acid was added, and the solution digested for many hours, nitric acid being added to keep up the oxidation until all organic matter was oxidized. The solution was then heated to copious evolution of SO_3 fumes, then cooled and diluted. The lead sulphate was filtered from the solution and purified by dissolving in ammonium acetate, and reprecipitated as sulphide. This sulphide was then dissolved and the lead reprecipitated as sulphate, which was weighed.

METHOD OF DETERMINING ARSENIC.

Five grams of the vegetation was treated directly in a flask with sulphuric acid and zinc, connected with the regular Marsh apparatus for collecting the arsenic. The amount of the arsenic collected was determined by comparing the mirrors with standard mirrors.

RESULTS OF DETERMINATIONS.

The results of the determinations were as follows:

Lead.—Weight of lead found in 254 grams vegetation, 0.0054 gram. Lead equals 0.0021 per cent, or 21 parts per million by weight. This is equivalent to 0.9 gram per 100 pounds of grass.

Arsenic.—Weight of arsenic in 5 grams, 0.000025 gram. Arsenic equals 0.0005 per cent or 5 parts per million by weight. This is equivalent to 0.2 gram per 100 pounds of grass.

SUMMARY.

A small quantity of lead and arsenic was present in the vegetation taken from the bluffs on the north side of the straits, between Dillon Point and Dos Reis Cove, at the end of the dry season. The amount found (21 parts lead per million and 5 parts arsenic per million of vegetation) represented the maximum deposit for a season. Inasmuch as the Selby smelter is the only known source of lead emanations in the vicinity, it must be concluded that the lead came from the Selby smelter.

DETAILS OF METHOD FOR THE DETERMINATION OF SMALL AMOUNTS OF SULPHUR DIOXIDE IN THE ATMOSPHERE.

NECESSITY OF TAKING "INSTANTANEOUS" SAMPLES AND MAKING RAPID ANALYSES OF SULPHUR DIOXIDE IN THE SAMPLES.

When the atmosphere is contaminated by noxious gases discharged from industrial plants, the amount of these gases present at any point in the vicinity is usually variable, even though the volume of the gases being discharged is a constant quantity over a long period of time. These variations in the concentration of the contaminating gases are due primarily to changes in the direction and velocity of the wind, and are influenced by changes in atmospheric pressure, humidity, and temperature. Not only is the concentration affected by general wind conditions, but local wind currents play an important part. Slight changes in the wind, or in barometric or temperature conditions, may produce very great changes in the concentration of the gases, so that even during a period of several minutes the amount of the gases present may vary between zero and a concentration many times greater than the average. Thus, a knowledge of the average concentration of the gases in the air at any point for a period of days or even hours may not be sufficient to indicate whether the gases were present momentarily to such an extent as to be a nuisance to people or a possible cause for damage to plant life.

In order to make a detailed study of the extent to which the atmosphere in the so-called "smoke zone" of a smelting plant is contaminated by the sulphur dioxide gas emitted from the stacks of the smelter, it is as necessary to determine these variations in the sulphur dioxide content of the air as it is to determine the average content during any period. The determination of the range of these variations necessitates the taking of a great number of samples, the taking of each sample in a brief interval of time, say less than 30 seconds, and sufficiently often to include the maximum and minimum concentration during any period. To carry out this scheme, it is desirable to have a quick and sensitive volumetric method for the analysis

of the samples; otherwise a considerable number of sample containers are necessary.

For the determination of the average sulphur dioxide content of the air during a period of a day or several hours, there are several methods applicable. The methods most commonly used are based on the aspiration of a measured volume of air through absorption bottles, or towers, containing solutions of caustic alkali, alkaline carbonates or bicarbonates, or iodine. The sulphur dioxide is oxidized and dissolved by the solution and subsequently determined as barium sulphate. In determining the average total sulphur content of the air, a method based on this principle has been used by the Selby Smelter Commission.

For several reasons, none of these aspiration methods is applicable for the rapid determination of sulphur dioxide. For the collection of a gravimetrically determinable amount of sulphur dioxide from highly diluted air, it is necessary to aspirate a relatively large sample; an operation that with any feasible field apparatus would require a considerable length of time. The aspiration must be carried out in such a manner that the last traces of sulphur dioxide will be completely removed. This would eliminate the possibility of aspirating above a certain rate. If the atmosphere contains sulphur trioxide or sulphuric acid fume or vapor, these constituents will be included in the samples and, if calculated to sulphur dioxide, will give high results.

ESSENTIAL FEATURES OF METHODS USED BY THE COMMISSION.

In the investigations for the Selby Smelter Commission, the determinations of sulphur dioxide in the atmosphere were made by methods that fulfilled the desired conditions, in that they allowed (1) the taking of a satisfactory sample in less than 15 seconds' time; (2) the rapid volumetric determinations of the sulphur dioxide in the sample, an operation requiring less than 5 minutes; (3) the determination of minute quantities of sulphur dioxide with a reasonable degree of accuracy.

For the primary novel features of these methods, we are indebted to Mr. J. R. Marston, chief chemist at the Selby smelter. These novel features comprise:

1. The method of running a "blank" simultaneously and in the same manner as the "sample" determination; this "blank" being run on an equal volume of air which, previous to a test, had been treated with an oxidizing agent to oxidize any reducing constituents that might be present.

2. The method of titrating the sulphur dioxide in the sample with iodine in a starch solution and obtaining the end point of the reaction by comparing the colors of the "sample" and "blank" solutions;

the iodine required to give to the "sample" solution the same color as the "blank" being the equivalent of the sulphur dioxide in the sample.

During the first few weeks of these investigations, the method used was similar in detail to the original method of Mr. Marston. Due to the fact that in this method there are present certain sources of error, though these errors were found to be of slight importance as affecting the results obtained by analyses of air in the Selby smoke zone, it was thought desirable to devise a modification of this method which would eliminate them.

A description of Marston's method as adopted for work of the Selby Smelter Commission is given below. This is followed by a discussion of the investigations made to determine the accuracy of the method, both in regard to the completeness of the chemical reaction involved, and in regard to manipulative details. A detailed description is then given of the method, modified in mechanical details as finally adopted to correct certain sources of error inherent in the original method. This is followed by a brief description of an official test of this adopted method made by several interested chemists.

Each method is dependent on the reaction between iodine and sulphur dioxide in aqueous solution as represented by the equation

$$I_2+SO_2+2H_2O=2HI+H_2SO_4$$
$$255 \text{ grams } I_2=64 \text{ grams } SO_2.$$

Thus, 1 c. c. N/500 iodine solution is equivalent to 0.000064 gram SO_2, equal to 0.0224 c. c. SO_2 at 0° C. and 760 mm.

DESCRIPTION OF MARSTON'S METHOD, ADAPTED TO WORK OF THE COMMISSION.

APPARATUS REQUIRED.

Sample bottles.—Two 24-liter aspirator bottles were used for containers. The bottles were made of the same kind of white glass. They were equipped with rubber stoppers at the top and bottom tubulures.

Test bottles.—Two 500-c. c. glass-stoppered specimen jars of uniformly clear white glass were used as "test" bottles. On the outside of each bottle, covering the lower half, except over a vertical strip 5 to 7 cm. wide, was pasted a uniformly white paper as a background for color comparisons.

SOLUTIONS REQUIRED.

The solutions required are as follows:

Iodine solution, containing 0.255 gram iodine per liter = N/500 iodine.

Starch solution, containing 1 gram starch per liter.

The starch solution is best prepared by making a paste of the starch in cold water, adding it to the boiling water, and continuing the boiling for five minutes.

The solution is kept in tightly stoppered bottles protected from sunlight. Starch solution one day old was the most sensitive to color changes. The addition of potassium iodide, about 2 grams per liter, served to make the end point more sensitive.

PROCEDURE.

Preliminary operation.—To one aspirator is added 250 c. c. of the starch solution containing a slight excess of iodine. The aspirator is then stoppered and shaken vigorously for about two minutes, more iodine being added, and the aspirator reshaken if the blue color of the starch solution is discharged. This oxidizing solution is then poured to waste and the aspirator tightly stoppered. Being thus freed from sulphur dioxide or other possible iodine reducing gases, this aspirator is used as a "blank" when making the determination of a "sample."

Sampling.—The second aspirator is then filled with clear water to which has been added a few drops of a strong starch solution and sufficient iodine to bring the water to a faint blue color. This was found to be necessary as all water, distilled or tap water, has been found to have a variable iodine reducing factor. To take the sample the aspirator is emptied of the water through the lower tubulure, the air simultaneously entering through the top tubulure. During this operation care is taken not to let the surface of the water become agitated. The aspirator is completely emptied of its water content in about 15 seconds, and then, when completely filled with the air sample, is stoppered.

DETERMINATION.

To about 500 c. c. of the starch solution is added sufficient iodine to bring the solution to a desired blue color. This solution is then divided equally between the two test bottles. The solution from one test bottle is poured into the aspirator containing the sample, and from the other into the blank aspirator. Then, under the same conditions as to sunlight and temperature, the two aspirators are shaken vigorously in such a manner as to wet completely the inner surfaces and to bring the sampled air in contact with the starch iodide solution. In case the color of the sample solution is completely discharged during this operation, more iodine is added and the solution again shaken. The solutions are then transferred to the test bottles and their colors compared, sufficient standard iodine being added by burette to the sample solution to give it the same color intensity as that of the blank. From the total iodine required to bring the colors into coincidence is then calculated the amount of sulphur dioxide in the sample.

Using a good, clear, starch solution, an analyst with a little experience may easily detect a difference in color due to the addition of 0.1 c. c. of a N/500 iodine solution to 250 c. c. of the starch solution. As 0.1 c. c. N/500 iodine is equivalent to 0.0022 c. c. sulphur dioxide (at 0° and 760 mm.), simple calculation shows that less than 0.1 part sulphur dioxide in 1,000,000 parts of air by volume may be determined, using a 24-liter sample aspirator.

When a series of samples is begun and carried through to completion in a short period of time, it has been found necessary to give the blank a preliminary oxidation only at the start. However, if the blank is allowed to stand for an hour or more, especially on a warm, sunny day, experience has shown it to be necessary to prepare the blank afresh before starting a test.

INVESTIGATIONS TO DETERMINE ACCURACY OF METHOD.

The method described above was subjected to a very careful investigation to determine its accuracy and limitations under different conditions. This work was done in December, 1913, by Mr. G. N. Libby and Mr. R. J. McKay, under the direction of the writer at the Bureau of Mines laboratory in San Francisco.

In order to realize, in the laboratory, the conditions that exist in the field, where the preparing of blank aspirators, transferring of solutions, and analytical manipulations are done in an atmosphere containing sulphur dioxide, it was found necessary to devise some scheme for supplying air of known sulphur dioxide content.

APPARATUS FOR PRODUCING AND MAINTAINING A KNOWN MIXTURE OF SULPHUR DIOXIDE AND AIR.

By means of this apparatus a measured current of sulphur dioxide was continuously supplied to a known current of air drawn into a fan, where the two were thoroughly mixed and discharged into a room or booth, thus giving a known concentration of sulphur dioxide.

Figure 6 shows an arrangement for measuring the rate of flow of sulphur dioxide gas from a tank of liquid sulphur dioxide. (See also Pl. XII, *B*.)

The construction and use of the meter [a] is dependent upon the principle that the difference in pressure between the two ends of a capillary tube through which a stream of gas is flowing is a measure of the rate of flow of the gas.

In figure 6 *d* represents a tank of liquid sulphur dioxide under pressure. The rate of flow of gas from the tank is regulated by the valve at the top of the tank. The gas is conducted by glass connection to

[a] For the suggestion of the use of this type of meter, we are indebted to Dr. L. H. Duschak of the Bureau of Mines.

the capillary *a-a'*, which is joined by T-tube connections to the manometer. The difference in pressure between the two ends of the capillary is shown by the difference in level of the menisci *e* and *f*, which is measured on the meter stick *b*.

Before proceeding to any test, it was necessary to "calibrate" the capillary; that is, to determine the pressure differences or manometer readings for different rates of flow. This was accomplished by allowing the gas to flow through the capillary for a definite period of time, and with a constant pressure difference, into a solution con-

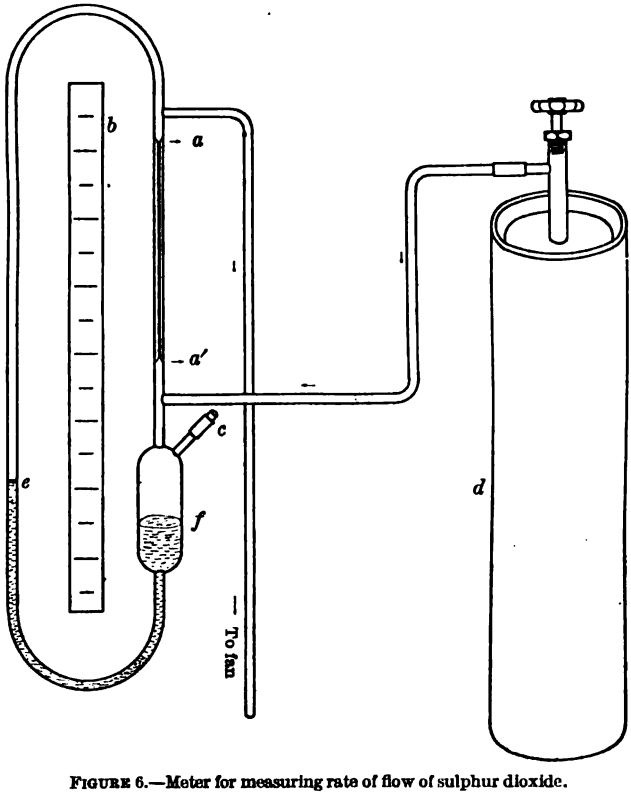


FIGURE 6.—Meter for measuring rate of flow of sulphur dioxide.

taining a known volume of standard caustic alkali or standard iodine, and determining by volumetric methods the sulphur dioxide delivered. The volume of sulphur dioxide delivered corresponding to four or five different pressure differences was determined for each capillary used. In plotting the pressure differences, or manometer readings, as abscissae, and the corresponding rates of flow, in cubic centimeters per minute, as ordinates, the curve for each capillary was obtained, which, for the range of volumes delivered in our tests, was practically a straight line.

After leaving the capillary the sulphur dioxide was conducted by glass tubing to the intake of a direct motor-driven forge blower. The air and sulphur dioxide mixture was then discharged into a mixing box of No. 18 galvanized iron, 36 inches long and 12 inches in diameter, containing 11 baffles. These baffles were 5 inches high and 3 inches apart, and were staggered so that the mixture had to zigzag through them. After passing through the baffle box, the mixture was conducted through a galvanized-iron pipe 48 inches long and 3¾ inches inside diameter, then through a galvanized-iron box 12 inches square by 18 inches long, from which the gases were discharged into the booth.

The booth, 6 feet long, 4 feet wide, and 6 feet high, was framed with wood and covered with a close-mesh duck cloth. At one end of the hood was a curtain flap, serving as an entrance. As the volume of air discharged into the hood by the fan was about 110 cubic feet per minute, there was maintained an excess pressure inside the booth, which prevented pure air from diffusing inward to dilute the mixture.

Six inches back from the discharge end of the 3¾-inch pipe Pitot tubes were inserted for the determination of the velocity, and thus the volume of the mixture being discharged. The Pitot tubes were of the type shown in figure 7 and were constructed in the Bureau of Mines laboratory.

The manometer used was the U-tube type, placed on a slope of 1 in 10, which allowed a considerable movement of the manometer liquid (alcohol) for a small velocity head. These Pitot tubes had been checked against a Pacific Gas & Electric 80-light gas meter, the measurements being made in a pipe 1.04 inches in diameter. Records of the Bureau of Mines show that for velocities up to 1,800 feet per minute, by applying a factor of 0.95, the velocities calculated from the Pitot tube readings were within 2 per cent of the actual velocities as calculated from the volume measured by the gas meter. From considerable experience with this and other types of Pitot tubes the writer was prepared to apply the factor 0.95 to the calculated results and feel certain that the results so obtained were within 2 per cent of the actual, and as the records of the Bureau of Mines checked up this factor, the Pitot tubes were not again tested.

The cross section of the pipe was explored carefully by these tubes under a wide range of velocities. With velocities ranging between 1,200 and 1,800 feet per minute the velocity in the center of the pipe was found to be 1.05 times the average velocity.

Through the baffle box and pipe, the fan discharged an average of 112 cubic feet or 3,200,000 c. c. of air per minute. In order to get a mixture of 1 part SO_2 per million parts of air, it was necessary to add 3.2 c. c. of SO_2 per minute, which could be measured with an accuracy of at least 5 per cent. Thus, with a mixture of 1 part in 1,000,000, we were sure that the liability of error was not greater

than 10 per cent at the most. As the concentration was increased to above 3 to 4 parts per million, the possible percentage of error in metering the sulphur dioxide became less, and the mixtures were undoubtedly within 5 per cent of the calculated.

From the preceding discussion it is evident that, allowing several minutes to elapse after starting to blow the mixture into the booth,

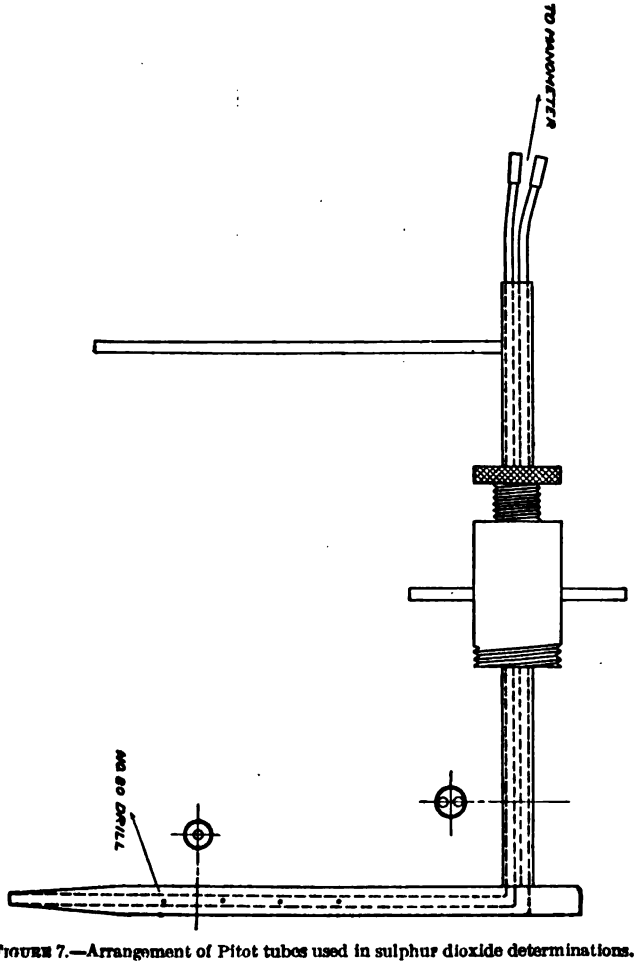


FIGURE 7.—Arrangement of Pitot tubes used in sulphur dioxide determinations.

the concentration of the sulphur dioxide in the air of the booth would be within 10 per cent of the calculated concentration for the most dilute mixture (1 to 5 parts per million) and within 5 per cent for stronger mixtures.

RESULTS OF TESTS TO DETERMINE ACCURACY OF MARSTON METHOD.

In order to test the accuracy of the method of analysis, it was necessary only to carry out the method in the booth in the same manner

as in the field. Tests were made with concentrations up to 14 parts SO_2 per million parts of air, with results as shown in the following table.

Results of tests to check Marston method of determination of sulphur dioxide in air.

Calculated mixture.			Volume of sample at 0° and 76 c. m.	N/500 I_2 used.	SO_2 equivalent to I_2 used.	Parts of SO_2 per million parts of air.	Actual SO_2 content divided by calculated content.
Air.	SO_2.	Parts of SO_2 per million parts of air.					
Liters.	*C. c.*		*Liters.*	*C. c.*	*C. c.*		*Per cent.*
3,000	1.6	0.5	22.2	0.6	0.0134	0.6	120
3,000	2.5	.8	22.2	.9	.0202	.9	112
3,000	3.2	1.1	22.2	1.1	.0246	1.1	100
3,000	4.3	1.4	22.2	1.5	.0336	1.5	107
3,000	4.3	1.4	12.4	.7	.0156	1.3	93
3,000	6.8	2.3	22.2	2.0	.0448	2.0	87
3,000	6.8	2.3	12.4	1.1	.0246	2.0	87
3,000	9.4	3.1	22.4	2.7	.0602	2.7	87
3,000	10.2	3.4	12.4	1.7	.0381	3.1	91
3,000	18.0	6.0	22.4	4.7	.1053	4.7	78
3,000	18.4	6.1	12.4	2.8	.0627	5.0	82
3,000	24.0	8.0	12.4	3.4	.0762	6.1	76
3,000	13.3	4.4	22.2	3.3	.0739	3.3	75
2,500	35.0	14.0	12.2	5.6	.1256	10.3	74

A brief study of this table shows that when working with concentrations of less than 3 parts per million the method gave results that checked up the calculated mixtures to within approximately 10 per cent. As the concentrations were increased above 3 parts per million, however, the determination was found to be always lower than the calculated mixture, the difference being approximately 20 per cent with a calculated mixture of 5 to 6 parts per million, and 25 per cent with higher concentrations.

INVESTIGATIONS TO DETERMINE CAUSE OF LOW RESULTS OBTAINED BY MARSTON METHOD.

Due to the fact that in this method the chemical reactions involved take place in a very dilute solution of the reacting agents, the question arose as to whether or not the reaction is quantitative at that great dilution. There was also a question concerning the possibility of a partial oxidation of the sulphur dioxide by the oxygen dissolved in the starch solution giving a low iodine titration. Inasmuch as the titrations checked the calculated mixtures more closely on the smaller concentrations of sulphur dioxide, this possibility did not seem reasonable. Nevertheless, it was decided to investigate the question carefully.

Ten c. c. of SO_2 at 16° C. was measured in a burette over mercury. The gas was diluted with air at 16° C. to 100 c. c. Twenty c. c. of this mixture was again diluted to 100 c. c. with sulphur dioxide free air. The second mixture was again diluted 25 to 100 c. c. so that

the resulting mixture contained 0.5 per cent SO_2 by volume, or 1 c. c. at 16° C., equal to 0.0000135 gram of SO_2.

Two aspirators were given a preliminary oxidizing wash with a slightly colored starch iodide solution, as previously described. To each aspirator was then added starch solution containing a slight excess of iodine. A glass stopcock having been inserted through the top rubber stopper, one aspirator was slightly evacuated. A measured volume of the mixture of sulphur dioxide and air from the burette was added to the aspirator, and after the air necessary to fill the partial vacuum had been admitted, the stopcock was closed. The aspirators were then shaken as in the regular analytical method about 60 times, then the theoretically required volume of N/500 iodine was added to the aspirator containing the sulphur dioxide, and the aspirators were shaken again. The starch solutions were then removed to the test bottles and iodine added to either the determination or the blank to bring the solutions to the same color. Results are given in the following table:

Results of tests to determine quantitative accuracy of reaction at high dilution, using gas and air mixtures.

Quantity of 0.5 per cent SO_2 mixture used at 17° C.	Parts of SO_2 per million parts of air in aspirator.	Quantity of SO_2 added.	N/500 I_2 used.	SO_2 equivalent to I_2 used.	Proportion recovered by titration.
C. c.		*Grams.*	*C. c.*	*Grams.*	*Per cent.*
2	0.42	0.000027	0.5	0.000032	118
3	.63	.000040	.6	.000038	95
5	1.04	.000068	1.0	.000064	94
8	1.67	.000108	1.7	.000109	101
10	2.10	.000135	2.2	.000141	104
15	3.13	.000202	3.5	.000224	111
20	4.17	.000270	4.1	.000262	97
40	8.34	.000540	8.9	.000570	105
60	12.50	.000810	12.5	.000800	99
.....	.....	.....	.....	.....	[a] 103

[a] Average.

As a second method of determining the quantitative accuracy of the reaction between sulphur dioxide and iodine in dilute solutions, the following tests were made:

An N/100 solution of sulphur dioxide was prepared by absorbing 120 c. c. of pure SO_2 at 18° C. and 760 m. m. in 1,000 c. c. of water. The normality of the solution was checked by titrating against a standard solution of KOH, using phenolphtalein as an indicator. Twenty c. c. of this solution was then diluted to 100 c. c. Thus 1 c. c. solution equaled 0.000064 gram of SO_2. This solution was kept in a tightly stoppered burette away from the sunlight and was used immediately. The solution was added in amounts as shown in the following table, to a 24-liter aspirator that had been given an oxidizing

wash as usual. Two hundred and fifty c. c., or one-half of a starch solution, faintly colored by a slight excess of iodine, was added and the aspirator shaken 60 times. Then the volume of iodine calculated for the sulphur dioxide in the aspirator was added and the aspirator again shaken. The solution was then transferred to a test bottle for titration to bring the color to coincide with that of the other half of the starch solution, which had been shaken in a similar manner in the blank aspirator. These data follow:

Results of tests to determine quantitative accuracy of reaction at high dilution, using sulphur dioxide solutions.

Quantity of N/500 SO_2 added.	Quantity of SO_2 in aspirator.	Quantity of N/500 I_2 used.	Equivalent SO_2.	Proportion recovered by titration.
C. c.	*Grams.*		*Grams.*	*Per cent.*
0.1	0.0000064	0.1	0.0000064	100
.3	.0000192	.3	.0000192	100
.6	.0000384	.6	.0000384	100
1.0	.0000640	.9	.0000576	90
2.0	.0001280	2.1	.0001340	104
3.0	.0001920	2.9	.000186	97
5.0	.000320	5.0	.000320	100
10.0	.000640	9.8	.000626	98
50.0	.003200	49.6	.003180	99

From the results of these tests it is concluded that the reaction $SO_2+I_2+2H_2O=2HI+H_2SO_4$ is quantitative at the dilutions used in this method.

In connection with these tests, however, it was found incidentally that if the titration was made with iodine to the initial appearance of the blue the results were more variable and averaged slightly lower than if obtained by color comparison with a blank. It was also found that if a considerable excess of iodine was used and a titration was made back to the disappearance of the blue using a sulphur dioxide solution, the results were also variable and generally high.

After we had determined that the fundamental chemical reaction involved takes place quantitatively and that the method of titration gives consistently accurate results, it remained for us to determine where errors were introduced mechanically by manipulation details.

MECHANICAL SOURCES OF ERROR.

Without going into any detailed account of the tests to determine these errors, a summary of the conclusions is given below:

1. When samples of air are taken over water, even though the surface of the water is quiet and the aspirator is emptied in less than 20 seconds, there is an appreciable absorption of the sulphur dioxide from the air sample as it comes in contact with the surface of the water which is being displaced. With concentrations of less than 2.5 to 3 parts per million, the amount so absorbed is hardly determinable.

With greater concentrations, however, the sulphur dioxide so dissolved is appreciable and seriously decreases the accuracy of the results.

2. During the process of transferring, by pouring the starch solution into or out of the "blank" aspirator, surrounded by an atmosphere containing sulphur dioxide, there is an appreciable dispersion of the outside air into the blank aspirator. The result of this dispersion is to lower the amount of sulphur dioxide apparent in the sample by an amount equal to the sulphur dioxide carried into the blank.

Likewise, if the sample aspirator is opened to receive the starch solution in an atmosphere containing a greater or less concentration of sulphuric dioxide than present in the aspirator, the dispersion during that time introduces errors for which no correction can be applied.

EXAMPLE.

A 24-liter aspirator was opened for definite periods of time in a booth containing 5 parts SO_2 per million parts of air. The sulphur dioxide diffused into the aspirator was then determined by carrying out the regular procedure in a room containing no sulphur dioxide.

Results of experiment to determine sources of error.

Time aspirator was opened in booth.	N/500 iodine required.	Equivalent parts of SO_2 per million.
Seconds.	*C. c.*	
0	0.0	0.00
5	.2	.18
10	.4	.35
20	.5	.45

3. There was also the direct solution of sulphur dioxide of the surrounding atmosphere in the starch solution during the process of pouring the solution into or out of the aspirators. Of course, the extent to which this direct absorption takes place should be the same in the blank as in the sample solutions, and by carrying out the process under the same conditions there should be no appreciable error introduced. However, a possible element of error must be recognized therein, especially with high concentrations.

4. The action of the iodine in the starch solutions upon the rubber stoppers was found to be appreciable even after washing the stoppers thoroughly with stronger iodine solutions. From this fact it was evident that unless the blank and sample aspirators were treated in about the same manner in regard to allowing the solutions to come in contact with the rubber stoppers, a source of error was introduced.

5. The moistened surfaces of the rubber or glass stoppers were exposed to the air containing 4 or 5 parts SO_2 per million for 15 or 20

seconds. There was found to be an appreciable absorption of sulphur dioxide on the surfaces, which would be a possible slight source of error.

6. Having allowed the blank aspirator to stand a half hour or so, after a determination has been made, it is essential to reoxidize the atmosphere and glass surfaces of the aspirator before using it again as a blank. Occasionally, especially during hot sunny conditions, there is a distinct iodine titration of the blank at the end of a half hour.

7. The necessity of using a blank solution and of treating that solution in a blank aspirator in a manner similar to the sample was made apparent. No constant factor for correction could be applied for the color change in the iodine solution was influenced by the light, temperature, and length of time that the solution was contained in the aspirator.

8. As a result of these tests, it was concluded that in the mechanical manipulation of this method, especially in the manner of taking samples and of transferring the starch solution to and out of the aspirator bottles, there are sources of error which account for the low results obtained when analyzing samples containing more than 3 or 4 parts of sulphur dioxide per million.

GENERAL CONCLUSIONS.

In determining the sulphur dioxide in air containing less than 3 or 4 parts sulphur dioxide per million parts of air the method is sufficiently accurate for all practical purposes. With higher concentrations, however, it is desirable to use a method whereby the sources of error, introduced mechanically by this method, are eliminated.

In order to eliminate the sources of error found to be present in the first method of analysis, the following method was devised, carefully tested out, and was subsequently used in field work for the commission during March, April, and May of 1914.

As this method is probably the most accurate and sensitive of any that has been used for the determination of small amounts of sulphur dioxide in the air it will be described here in considerable detail.

DESCRIPTION OF SELBY SMELTER COMMISSION METHOD FOR DETERMINING SULPHUR DIOXIDE IN AIR.

APPARATUS.

Sample bottles.—Two 24-liter aspirator bottles are used for sample containers (figs. 8 and 9). The bottles are of the same kind of glass, so that the action of heat and light on the iodine will be the same in each. The top tubulure of each aspirator is closed by a rubber stopper through which a glass stopcock, *a*, is inserted. In the lower

tubulure is placed a one-hole rubber stopper, *b*, in which is fitted a glass plug extending for about 1½ inches outside the stopper.

Test bottles.—Two test bottles are used, each a 500-c. c. wide-mouth specimen jar, of uniformly clear white glass. (See figs. 8 and 9.) Each bottle is equipped with a three-hole rubber stopper. Through one opening of the stopper is inserted a glass tube of about 4-mm. diameter, bent at right angles (tube *c*, fig. 8).

Through the second opening is inserted a tube, *d*, of about 2-mm. bore, extending nearly to the bottom of the bottle and closed on the outside by the cap *e*. In the third hole is inserted a glass tube, *f*. On the outside of the bottles, covering the lower half, except over a vertical strip 5 to 7 cm. wide, is pasted a uniformly white paper to serve as a background for color comparison.

Mixing bottle.—A 1,000-c. c. wide-mouth specimen jar is equipped with a three-holed rubber stopper. In one hole a 4-mm. bore tube is inserted reaching to the bottom. In the other two holes are inserted glass rods as stoppers.

Burette.—For the purpose of discharging the iodine solution well inside the test bottles when titrating, the burette is equipped with a long small-bore delivery tube.

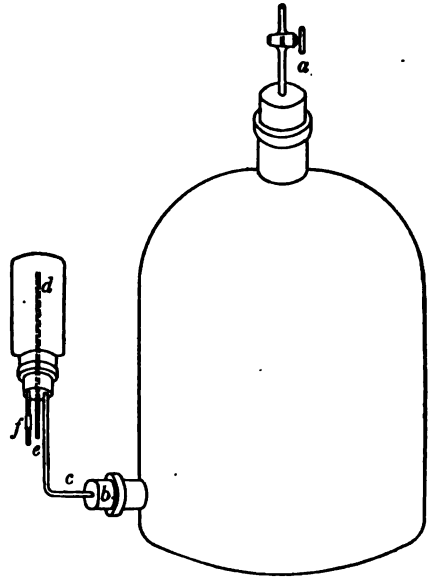


FIGURE 8.—Sample bottle and test bottle arranged for transferring solution from test bottle into sample bottle.

Vacuum pump.—For evacuating the sample bottle, we used a cylindrical hand pump, or a large wheel-operated pump that had been obtained primarily for use in connection with total-sulphur determinations and which will be described later. The vacuum gage is a calibrated mercury column.

SOLUTIONS REQUIRED.

Iodine solution.—0.255 gram iodine per liter = N/500 normal.

1 c. c. N/500 solution = 0.000064 gram SO_2 = 0.0224 c. c. SO_2 at 0° C. and 760 mm.

Starch solution.—Either soluble starch or grain starch may be used for making the starch solutions. With either, about 1 gram of starch per liter of water gives the most satisfactory solution. It is best prepared by adding the starch in paste form to boiling water, boiling for

several minutes, then cooling slowly. The addition of potassium iodide, 2 grams per liter, was found to render the color comparison more sensitive.

PRELIMINARY PROCEDURE.

About 500 c. c. of the starch solution is brought to a desired light-blue color with iodine in the mixing bottle. One-half of this starch iodide solution is then transferred to each test bottle. To make the transfer so that the solution will not come in contact with the air, the tube *c* (fig. 8) of the test bottle is inserted in one of the holes of the stopper of the mixing bottle. The tube *f* (fig. 8) of the test bottle is opened. The mixing bottle is inverted and the solution run into the test bottle through *c* (fig. 8).

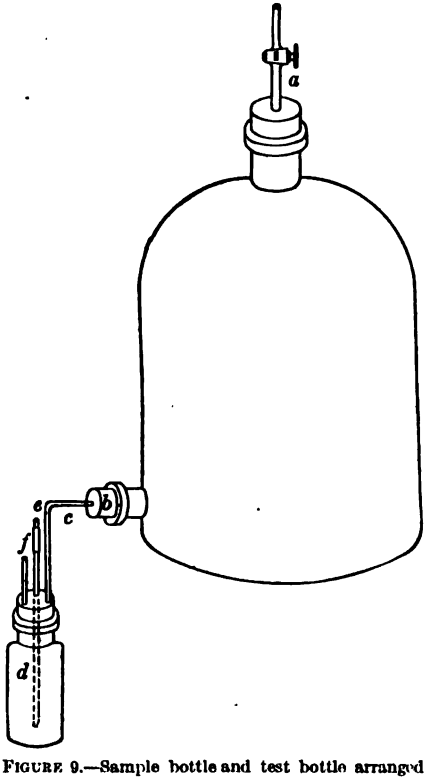


FIGURE 9.—Sample bottle and test bottle arranged for transferring solution from sample bottle to test bottle.

Having transferred the solution to the test bottles, the colors of the solutions in the test bottles are compared carefully to make sure that they are coincident, and that no dirt or film on the glass obscures the colors.

The solutions are then transferred to the aspirators. This is accomplished, with the test bottle and the sample bottle arranged as shown in figure 8, by inserting the tube *c* (fig. 8) of the test bottle into the hole of stopper *b* of aspirator, removing the cap *e* from tube *d*, inverting the test bottle and opening the glass stopcock *a* of the aspirator. The solution having been transferred, the glass stopper is replaced in *b*, and *a* closed. The aspirators are shaken vigorously for about five minutes to wash them and to oxidize any reducing gases that might be present in the aspirator. The solutions are then transferred back to the test bottles through the tube *c*, by holding the test bottles under the aspirators, opening the glass stopcock *a* of the aspirators and the glass tube *f* of the test bottles (see fig. 9).

Having transferred the solutions back to the test bottles, the colors of the solutions are then compared. If the two solutions have the same color, the aspirators are considered ready for analytical

work. If the colors are not the same, the starch solutions are again mixed, transferred to the test bottles and to the aspirators as before. The aspirators are again shaken, the whole operation being repeated until after removal from aspirators, the solutions are of the same color, or can be brought to the same color by the addition of not more than 0.1 c. c. N/500 iodine to the lighter one.

SAMPLING.

Having washed the aspirators sufficiently so that their iodine consumption factors are zero, or a constant for both, a fresh starch iodide solution is divided between the two aspirators as before, 250 c. c. to each. One aspirator is then evacuated by pump to a 380-mm. vacuum. Both aspirators are then carried to the point where the sample is to be taken, care being taken that both aspirators have the same exposure to sunlight. The sample is taken by opening the stopcock *a* (fig. 9) of the evacuated aspirator, the volume taken in being that required to bring the pressure in the aspirator back to atmospheric conditions.

DETERMINATION.

The two aspirators are then shaken vigorously 60 to 80 times in such a manner that the sample and solution are brought into intimate contact, the "blank" being shaken in the same manner as the determination. The starch solutions are then transferred to the test bottles in the manner previously described. The colors of the solutions are then compared, and by means of the burette sufficient N/500 iodine solution is added through the hole *f* (fig. 9) in the "determination" bottle to bring the color to that of the "blank." In cases where the color of the determination solution is very much lighter than the blank, or is completely discharged, this solution is titrated to a color slightly deeper than that of the blank, the two solutions are returned to their respective aspirators, the aspirators are again shaken and the colors compared as before. Following this procedure, it is evident that, provided the determinations are made not more than 30 minutes apart, each determination prepares the aspirators for the following determination, thereby eliminating the necessity of going through the preliminary oxidation process each time.

As stated previously, in discussing the first method, with a little experience and using a well-prepared starch solution an analyst can detect, by comparison, a change produced by the addition of 0.1 c. c. of N/500 iodine to 250 c. c. of the starch solution.

EXAMPLE.

Temperature of air, 16° C.
Barometric pressure, 760 mm.
Capacity of aspirator, 24.2 liters.
Extent of evacuation, 380 mm.
Volume, $24 \times \frac{380}{760} \times \frac{273}{289} = 11.3$ liters at 0° C. and 760 mm.

Titration, 0.1 c. c. N/1000 iodine=0.1×0.0224=0.00224 c. c. SO_2 at 0° C. and 760 mm.

$$SO_2=\frac{.00224}{11,300}$$
$$=0.00002 \text{ per cent.}$$
$$=0.2 \text{ part per million, by volume.}$$

SPECIAL NOTES.

In the course of working out the details of manipulation for this method it was found to be much more satisfactory to introduce the starch solution into the aspirators before evacuating than to introduce it later after the sample was contained in the aspirator. With the starch solution present in the aspirators when the sample was being taken the aspirator could be shaken immediately, which eliminated any possibility of the disappearance of sulphur dioxide by oxidation or adsorption in contact with the alkaline surface of the glass. There was no appreciable loss of iodine from the starch-iodine solution during evacuation.

One of our field-apparatus sets, the automobile laboratory, was equipped with 12 to 14 liter aspirators. For the purpose of getting the full 12 to 14 liter capacity as a sample we tried the method of connecting the aspirator with the pump and drawing through a large volume of air; for example, 50 or 60 liters, taking the last 12 liters as a sample. Not only did this method take considerable time, but it introduced very grave errors. Unless the aspirator was absolutely dry, requiring a treatment of alcohol and ether, there was a surprisingly large and variable adsorption of the sulphur dioxide from the first 40 or 50 liters that passed through the aspirator, the amount adsorbed being different for different degrees of dryness of the aspirator. When aspirators that had been allowed to drain only for several minutes were used, the adsorption was great, and was due undoubtedly to reaction with alkali or solution in water, or both. Thus, as it was not possible to dry the aspirators satisfactorily in the field, this method of taking a sample was not considered desirable.

However, it was found that with a 12 to 14 liter aspirator 150 c. c. of starch solution was sufficient for washing the sulphur dioxide from the sample. With this smaller sample 0.1 c. c. of an N/1000 iodine solution gives a satisfactory color change, and the degree of accuracy in titration was thereby as great as with the large samples.

The details of the many tests made to determine the accuracy of this method need not be given here. They established that the method is accurate with all concentrations liable to be encountered in any contaminated atmosphere. The method is rapid and the manipulation is not difficult.

OFFICIAL TEST OF MODIFIED METHOD.

On May 20, 1914, an official test of the method was carried out in the laboratory of the Bureau of Mines in the presence of the following chemists: Ralph A. Gould and E. C. Franklin, of the Selby Smelter Commission; A. E. Wells and R. J. McKay, of the commission staff; L. H. Duschak and G. C. Bartells, jr., of the Bureau of Mines; J. R. Marston, of the American Smelting & Refining Co., Selby plant; and E. P. Fleming, of the American Smelting & Refining Co., Utah department.

A brief summary of this test will be given here.

An N/100 iodine solution was prepared and standardized by titration with N/100 sodium thiosulphate solution (2.48 grams of $Na_2S_2O_3.5H_2O$ per liter). Fifty c. c. of this standardized N/100 solution was diluted to 250 c. c., giving an N/500 solution.

A sulphur dioxide mixture was prepared in a burette over mercury by successively diluting the pure SO_2 gas with air, the resulting gas containing 0.1 per cent SO_2 by volume.

10 c. c. SO_2 diluted to 100 c. c. = 10 per cent SO_2 mixture (1).
10 c. c. of mixture 1 diluted to 100 = 1 per cent SO_2 mixture (2).
10 c. c. of mixture 2 diluted to 100 = 0.1 per cent SO_2 mixture (3).

The aspirators and test bottles used were a set sent to the laboratory from a field station and had been thoroughly cleaned and washed. The aspirators were then oxidized with a starch-iodine solution containing a slight excess of iodine until upon removal from the aspirators the solutions exactly corresponded in color. The determinations were made in the usual manner by adding the starch solutions to the aspirators, slightly evacuating one aspirator, adding a definite volume of the known mixture, and determining in the regular manner the sulphur dioxide so added.

Results of determinations.

Volume of mixture added.	Mixture used.[a]	Volume of SO_2 at 0° C. and 760 mm.	Quantity of N/500 I_2 used.	Quantity of SO_2 equivalent to I_2 at 0° C. and 760 mm.	Proportion of SO_2 recovered.
C. c.		*C. c.*	*C. c.*	*C. c*	*Per cent.*
45.6	2	0.452	18.9	0.423	98
38.6	3	.366	1.7	.381	104
20.0	3	.019	.8	.018	95

[a] See above.

The following tests of the method were made, using mixtures in a booth prepared by the fan-and-meter apparatus previously described.

Results of tests.

Calculated volume of SO_2 in hood.	Volume of sample at 0° C. and 760 mm.	Net quantity of N/500 I_2 used.	Volume of SO_2 as determined by analysis.	Proportion of calculated amount.
C. c.	*C. c.*	*C. c.*	*C. c.*	*Per cent.*
3.2	11.4	1.9	3.7	116
3.2	11.4	1.9	3.7	115
(a)	11.4	.1	.2	.....
.7	11.4	.4	.8	115
5.0	11.4	2.4	4.7	94
13.8	11.4	7.25	14.5	105

a Air from window.

At the time of the above tests an experiment was made to illustrate the danger of obtaining erroneous results by drawing through the sample aspirator a volume of air much greater than the final sample. A 2.5-liter aspirator was washed and drained. Through this was drawn in five minutes 12 liters of air containing 6 parts sulphur dioxide per million parts of air. The final 2.5 liters was taken as a sample and analyzed in the usual manner by titrating with iodine in starch and comparing colors with a "blank." The sulphur dioxide recovered by analysis corresponds to 19.8 parts sulphur dioxide per million, whereas the mixture contained only 6 parts per million.

FIELD NOTES.

When using this method for analyses of the air in the "smoke zone" of a smelter, the following notes should be recorded:

1. Time.
2. Temperature of air.
3. Barometric pressure.
4. Direction of wind.
5. Approximate velocity of wind.
6. Capacity of aspirator used.
7. Initial vacuum in aspirator.
8. Iodine titration, c. c. N/500 solution.

From the above is calculated:

1. Volume of sample at 0° C. and 760 cm.
2. Volume of sulphur dioxide equivalent to iodine.
3. Ratio of sulphur dioxide to air, parts per million.

METHOD FOR THE DETERMINATION OF THE TOTAL SULPHUR IN THE ATMOSPHERE PRESENT AS DIOXIDE OR TRIOXIDE.

For the determination of total sulphur present in the air, either as dioxide or trioxide, or the average sulphur dioxide present in the air during a considerable period of time, the following method was used.

METHOD.

A measured volume of air was aspirated through a suitable absorption apparatus containing solutions in which the sulphur dioxide was oxidized and dissolved and in which the trioxide, either in the form of vapor or fume, was also absorbed. The sulphur so collected was then determined gravimetrically as barium sulphate.

APPARATUS.

The absorption apparatus (fig. 10) consisted of a train of three glass tubes, 4.5 cm. inside diameter, and 110 cm. long, about four-fifths of each tube being filled with glass beads. Over the top of each tube was fitted a glass cap, *k*, the joint being made tight by a thin rubber gasket. Through the top of each cap was inserted and sealed a 100-c. c. separating funnel, *c*, and also an outlet tube, *g*, 0.6 cm. inside diameter, bent as shown in the illustration. To the bottom of each tube was welded a glass stopcock, *f*, and an outlet tube, *h*, 0.6 cm. diameter. The outlet tube, *g*, of one tube was connected to the inlet, *h*, of the next following by a glass tube, *d*, of the same diameter, the glass joints, *i*, being made tight, glass to glass, so that the rubber tubing on the outside was not exposed to the action of the gases or fumes from the inside. At a point 5 cm. from the bottom of each tube, the glass was so indented as to provide a seat for a pad of glass wool 2 cm. thick, which held the glass beads in place.

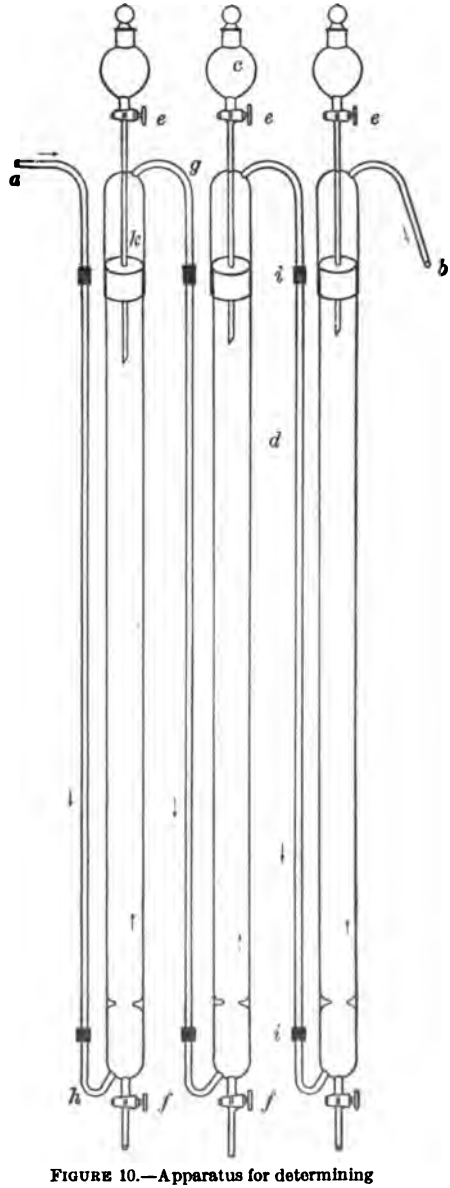


FIGURE 10.—Apparatus for determining total sulphur present in atmosphere as dioxide or trioxide.

In order to maintain a steady flow of air through the absorption train entering at *a* and leaving at *b*, and at the same time to measure the volume accurately, a steel tank of known capacity was evacuated to a known degree, then connected to the absorption train and the air drawn through the train until the pressure in the tank was brought back to a known point. The tank used had a capacity of 116 liters or 4.06 cubic feet. For evacuating the tank there was used a hand-wheel-driven double-cylinder pump superimposed on the tank itself. The pump and tank arrangement was a standard combination beer pump manufactured by the Cleveland Faucet Co., the valves being changed to produce vacuum rather than pressure in the tank. The apparatus is shown in Plate XI, *A*, and Plate XII, *A*.

SAMPLE BOTTLES.

For the sample solution 500-c. c. glass-stoppered tincture bottles that were thoroughly washed to free them from possible contaminating salts were used as containers.

ABSORPTION SOLUTIONS.

In the first tower of the train a strongly oxidizing solution of either bromine or iodine was used. In the two following towers were used either a dilute ammoniacal, or a 0.2 per cent sodium bicarbonate solution. The aspiration of the air through the train carried bromine and iodine vapor over into the second tower, and even to the third, and it was necessary from time to time, during each test, to replenish these oxidizing agents in the first tower. Stock absorption solutions were made up with distilled water.

PRELIMINARY WASHINGS.

Before a series of tests was started, precautions were taken to assure having the apparatus, glass beads, etc., free from any soluble sulphates. This necessitated boiling the glass beads with strong acids, then repeatedly washing with distilled water and then with the stock solution to be used in the tests. The glass tubes and connections were given a warm acid treatment and then washed. Tests were also made to assure that no traces of sulphur could be introduced into the solutions by the action of bromine, iodine, or alkaline solutions coming in contact with any rubber tubing or gaskets. Even weak solutions were found to attack rubber to such an extent as to introduce an error in the determination, and no rubber surfaces were allowed to be exposed to the solutions.

SAMPLING PROCEDURE.

The solutions were introduced to fill the towers to above the top of the glass beads. The tank was evacuated to the desired vacuum, for example, 22 inches (560 mm.), and then caused to draw the sam-

A. TRAIN OF GLASS TUBES FOR ABSORPTION APPARATUS.

B. "CONCENTRATED" OR "KILL-BACK" TYPE OF BLEACH.

A. ABSORPTION APPARATUS.

B. SULPHUR DIOXIDE METER.

C. "MOTTLED" TYPE OF BLEACH.

ple through the towers at the desired rate, that is, about 1,300 c. c. per minute, until the vacuum was reduced to 7 inches (180 mm.). The tank was then evacuated again, an operation requiring from two to five minutes, and the aspiration repeated. At the beginning and end of each tank filling, the following data were recorded:

1. Time.
2. Temperature of air in tank.
3. Vacuum in tank compared with outside atmosphere.
4. Barometric pressure of outside air (aneroid barometer).

The total volume of each sample varied between 150 and 2,800 liters, but averaged about 570 liters, or 20 cubic feet. At the end of each sampling the solutions were drained from the towers through the stopcock *f* (fig. 10) into the tincture bottles. The first two tubes were washed with about 100 c. c. of the stock solution, and the washings added to the samples, which were tightly stoppered, marked, and sent to the laboratory for analysis. A considerable number of samples of stock solution were sent in as "blanks."

ANALYSIS.

The analyses of the samples were made by the usual gravimetric method for SO_3 in solution, care being taken to avoid errors incident to determining small quantities of SO_3.

When ammoniacal solutions were received they were made acid with hydrochloric acid, and then a slight excess of sodium bicarbonate was added. Each solution was evaporated to about 80 c. c., filtered, and washed, the washings increasing the volume to about 100 c.c. This solution was made very slightly acid, litmus paper being used as an indicator, and 2 or 3 c. c. of a 10 per cent barium chloride solution was added to the boiling solution. The solution was boiled for 10 minutes, then allowed to cool and stand for about 20 hours. The precipitate was then filtered through a proper filter, carefully ignited in a small platinum or porcelain crucible, and weighed as barium sulphate. Weights were recorded to the tenth of a milligram. From the gross weight, corrected for the ash of filter paper, was deducted the weight of barium sulphate precipitated with an equal volume of a "blank" solution, and the net weight taken as that due to the sulphur absorbed from the air samples.

ACCURACY OF RESULTS.

As the air was aspirated through columns totaling about 330 cm. (130 inches) in height, and the bubbles of air were well broken up continuously during the travel through the columns of glass beads, the conditions were excellent for the complete absorption of the sulphur dioxide and trioxide. Evidence of the practically complete absorption is found in the following table, showing the relative pro-

portions of sulphur recovered in the tubes, these figures being an average of 106 determinations:

Proportion of weight in first tube	69.4
Proportion of weight in second tube	22.0
Proportion of weight in third tube	8.6

In 71 tests the solutions from the second and third tubes were combined for analysis. In these tests 75 per cent of the total sulphur recovered was found in the first tube. Thus, in 177 tests, the first tube was found to contain over 71 per cent of the total sulphur. These ratios were found to be general throughout all the tests. From these ratios it was concluded that the sulphur found in the solutions represented, within at least 5 per cent, the total sulphur in the air aspirated.

With reasonable care in handling the solutions, there was but small possibility of contaminating the solutions with sulphur from an outside source.

Many determinations on the "blanks" were made, which indicated that the analytical work was accurate to about 0.3 miligram of $BaSO_4$. With a 570-liter sample 0.3 milligram $BaSO_4$ is equivalent to 0.05 part of SO_2 per million parts of air by volume.

AUTOMOBILE LABORATORY USED BY SELBY SMELTER COMMISSION.

Anyone who has ever attempted to determine the concentrations of sulphur dioxide in the atmosphere of the "smoke zone" of a smelter will agree that it is not satisfactory or advisable to try to obtain that data solely by making analyses at one or two fixed stations. If the locations of the stations are carefully chosen, very valuable information may be obtained at them. However, even with the best-located stations there will be many days when the smoke will not be in that vicinity, and, so far as the data desired are concerned, the stations are of little value.

Thus, to obtain the data concerning the smoke conditions over an extended area in a short time and under various atmospheric conditions, the use of an analytical apparatus capable of being moved quickly from one place to another is more expedient than to attempt to gain that information at several fixed stations.

Realizing the advisability of using a portable laboratory, especially as it was desired to obtain analyses of the air in many places outside the "smoke zone" of the Selby smelter, it was decided by the commission to design and equip a set of apparatus for that purpose on an automobile body.

For this purpose there was purchased a rebuilt E. M. F. 30-horsepower machine from which the rear seat had been removed and a

delivery-wagon body substituted. This body was 42 inches wide by 54 inches long. At the front of this body bed, backed up against the driver's seat, was built a wooden cabinet 36 inches long, 14 inches wide, and 42 inches high, divided into two parts. The upper part was 10 inches deep, and subdivided by 1-inch strips into 24 square pockets each large enough to hold tightly a 500-c. c. tincture bottle. Around the strips was wrapped felt cloth to prevent the glasses striking against wood. The top of this section swung up on hinges placed at the back.

Entrance to the lower section was obtained through doors that swung on hinges at the sides and locked at the center. The upper half of this section was equipped to hold ten 2,500-c. c. solution bottles. These bottles were held tightly in wooden brackets cut to fit the circumference of the bottles. These strips were held in grooves along the sides of the section and could be removed. The lower half of this section was equipped similarly to hold three 12 to 14 liter aspirator bottles. At all points where the glass and wood would come in contact the contact points were covered with felt.

This cabinet was elevated about 10 inches above the machine bed, so that the doors of the cabinet would swing clear of the second smaller chest placed in front. This second chest was 12 by 36 inches by 10 inches deep, with a top lid swinging on hinges at the back. This chest was subdivided into many small compartments to hold burettes, glass tubes, rubber stoppers, tubing, and a miscellaneous supply of small articles.

A third cabinet was placed against one end of the larger cabinet, with a door swinging outward. In this cabinet, 40 inches high by 10 inches wide by 6 inches deep, were placed the absorption towers, which were held tightly in place against felt cushions by brass straps wrapped with felt and strips of wood cut to surround the towers.

At the back of the machine was fastened by bolts the combination pump and steel tank used for drawing the air through the absorption towers. The tank could be evacuated by the operator while standing on the ground. To one post supporting the canvas cover of the outfit was attached a mercury manometer for measuring the vacuum produced in the aspirator used for instantaneous sulphur dioxide sampling. An extra nipple and valve were placed in the connection between the pump and tank, which allowed evacuating the aspirators without interfering with the regular aspiration procedure of the tank.

In place of closing the tops of the glass absorption towers with the regular glass caps cork stoppers were used. These were impregnated with paraffin and covered on the outside with sealing wax, making them perfectly air-tight. A 100-c. c. separating funnel and an outlet tube were inserted through the cork stopper. Otherwise the absorption train was the same as that described in the discussion of the

method to determine the total sulphur content of the air. A space on the machine body about 7 by 36 inches was left free to be used as a bench, the operator standing on the ground. The mud guards over the rear wheels also were used as benches at times.

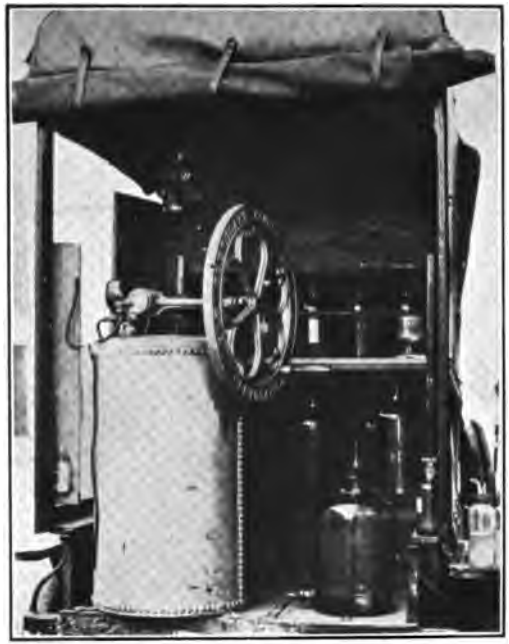
The apparatus was easily prepared for work. Six or seven minutes after arriving at a place the total-sulphur apparatus could be started drawing in a sample, and the analyst could be taking an "instantaneous" sample for sulphur dioxide determination.

Operated by an equally careful and neat analyst, the results obtained by this portable laboratory were as accurate as those obtained by the operators at the fixed stations.

During the seven and one-half months that this laboratory was in use no breakage of glassware, towers, etc., was caused by the jarring or bumping of the machine, which at times was obliged to travel over very rough roads.

By the use of this apparatus analyses of the air were made in San Francisco, Oakland, Berkeley, Richmond, Martinez, and in practically all the territory included in the so-called Selby smelter zone. Plate XIII shows the automobile laboratory.

A. AUTOMOBILE LABORATORY, SIDE VIEW.



B. AUTOMOBILE LABORATORY, REAR VIEW.

FUMIGATION EXPERIMENTS TO DETERMINE THE EFFECT OF HIGHLY DILUTED SULPHUR DIOXIDE ON A GROWING GRAIN CROP.

By A. E. Wells.

INTRODUCTION.

One of the causes that led up to the complaint by the people of Solano County against the smoke from the Selby smelter was the belief that the smoke was present in sufficient strength over the agricultural area of the "smoke zone" to be detrimental to and to do material injury to field crops and to orchards. The claims of such damage were made also to several representatives of the Selby smelter commission during the period of the investigations.

As a result of the great number of determinations of sulphur dioxide present in the atmosphere over the farming district west and northwest of Benicia during September to December, 1913, it was evident that occasionally there was present over this district a greater concentration of sulphur dioxide than is normally present in the atmosphere of most agricultural districts.

Thus, supplementary to the work of the expert agronomists and agriculturists of this commission, who were to determine the possibility of the crops having suffered through soil contamination, it became necessary to determine whether or not the crops had suffered or were likely to suffer from occasional fumigations with sulphur dioxide gas in the concentrations found over the "smoke zone."

GENERAL PLAN OF EXPERIMENTS.

A considerable part of the field crops in the Selby "smoke zone" is barley. This crop has been considered by most smoke investigators and plant pathologists as one especially susceptible to injury by sulphur dioxide. Thus, it was decided to carry out investigations with this grain. It was decided also to devote practically all the work to this crop alone, the idea being to get as much information as possible concerning the possible injury to a crop supposed to be the most susceptible to sulphur dioxide.

The original plan for these experiments was as follows:

1. To determine the visible injury brought about by fumigations with definite concentrations of sulphur dioxide and for definite periods of time.

2. To determine the effect of any visible injury upon the yield or total growth of the crop.

3. To determine the possibility of "invisible" injury and the extent to which this can take place.

In deciding upon a method for conducting these experiments, it was thought inadvisable to try to duplicate the methods used by previous investigators. In the earlier reported experiments along these lines, the plants under investigation were placed in pots or small boxes inside closed glass cabinets or houses. Measured volumes of sulphur dioxide were added to make a definite concentration when mixed with the air of the cabinet or house. The addition and mixing of this volume of sulphur dioxide with the air in contact with the plants was called a "fumigation."

The chief objections to using a method similar to the above to gain the information desired by our experiments were as follows:

1. Plants in pots or small boxes are not growing under conditions similar to those in the field, and the abnormal condition, even if slight, might influence the susceptibility of the plant.

2. The length of time during which the plants are subjected to the action of the calculated concentrations can not be determined, for the rate of absorption or disappearance of the SO_2 from the atmosphere of the cabinet can not be calculated.

3. Owing to the comparatively few plants that can be fumigated in this manner, no satisfactory determination of the yield can be made.

In our experiments, the aim was to fumigate under conditions that were not materially different from the normal. The barley was to grow in the open field, as usual, and only occasionally and for definite periods of time was it to be subjected to the action of a definite concentration of sulphur dioxide.

In order that the results of these tests should be applicable to the barley crops growing in the Selby district, it was necessary to select for our work a field of barley that would be growing under conditions similar to those of the other fields in the "smoke zone." The agronomical and agricultural conditions of the area had been studied by Mr. E. E. Free, Prof. Charles F. Shaw, of the University of California, and their field assistant, Mr. Ralph W. Brown. In the opinion of these representatives of the commission, average "agronomic" conditions of the smoke zone were met in a portion of the barley field owned by Mr. Philip Steffens on the north side of the Vallejo-Benicia road, about one-half mile east of the Vallejo limits.

This field lies north and west of the district where smoke nuisance has been claimed. From our field notes taken during September to December, 1913, it was evident that the smoke from the Selby plant seldom, if ever, was present in determinable amounts over this field.

Thus, the location of the field in its relation to the smelter was favorable.

The chief objection to the field was the poor cultivation. The ground had been plowed and then only roughly harrowed, so that the ground was very lumpy. The grain was sown rather unevenly. In spite of these objections it was evident that the field was about as well cultivated as most of the fields in the district and that the results from this field would be applicable for the Selby "smoke zone."

APPARATUS USED IN THE EXPERIMENTS.

The apparatus for preparing a definite and properly mixed concentration of sulphur dioxide in air (see fig. 10 and Pl. XII, *B*) has been described in detail in another section of this report. Sulphur dioxide gas drawn from a tank of the liquid is passed through a capillary meter into the intake side of a small blower, which delivers the mixture of sulphur dioxide and air into a galvanized-iron baffle box, and then into a galvanized-iron delivery pipe.

The motor of the blower was driven from a 110-volt A. C. power line, the power being carried from a central pole to the motor by extension cords.

The fumigation cabinets (Pl. XIV, *A*) were framed with wood, and covered on the top, sides, and ends with celluloid sheets 0.4 mm. thick. The front end of the cabinet had a round hole through which the delivery pipe from the blower was inserted. The back end was opened sufficiently to allow the escape of the air from inside. The cabinets were built 121 cm. wide, 610 cm. long, and 76 cm. high. The ground area thus covered was 7.4 square meters, the contents 5.6 cubic meters. After the first few weeks one of these cabinets was cut in half, and the halves, 305 cm. long, were used for certain experiments.

The cabinets weighed about 70 kilograms. They were equipped with handles at the ends and were easily carried from plat to plat by two men.

RECORDS KEPT IN THE EXPERIMENTS.

The volume discharged into the cabinet by the fan was determined by measuring, with Pitot tubes and a suitable manometer, the velocity of the air in the delivery pipe between the mixing box and the fumigation cabinet. All gas volumes referred to in the report of this work are at atmospheric temperature and pressure unless otherwise stated.

During most of the fumigations records were kept of the temperature and relative humidity of the outside air—that is, the air being blown into the cabinet. Records were also kept of the temperature and humidity at the farther end of the cabinet. Lloyd's hygrodeiks

were used for most of these readings, and these were checked from time to time by a sling psychrometer.

The calculated sulphur dioxide concentrations were checked very frequently by analyses. The method of analysis was the modified Selby Smelter Commission method used in the regular field work. At the beginning of the work analyses of the mixtures blown over the plants were made during every fumigation. Later the analyses were made over the range of concentrations used with each fumigation outfit, twice or three times per week. In nearly all cases the concentrations of the sulphur dioxide in the volume blown into the cabinet as determined by analyses checked within 10 per cent of the calculated concentrations. The concentration at the far end of the cabinets was invariably lower. This feature will be discussed below.

GENERAL DISCUSSION OF RESULTS.

After the first few experiments, it was evident that by this method of fumigation we were producing visible injury and bleaching on the vegetation with very much lower concentrations of sulphur dioxide than were thought could possibly do damage. Because of this discrepancy from the results reported by previous investigators, we have investigated very carefully the conditions that could influence the susceptibility of the grain. Furthermore, we have carried on experiments both in the field and in the laboratory, using the method of fumigation employed by many previous investigators, and are able to show wherein lies the cause for the discrepancy of these from earlier reported results.

The first fumigations were of comparatively long duration. Most of them were of one-hour duration; one was continued for four hours; and one for eight hours per day. Check plats were fumigated at the same time with the atmosphere of the field which contained no determinable amount of sulphur dioxide. Inasmuch as the check plats showed no signs of injury whatever, except an occasional mechanically bruised leaf at one or the other end of the plat, it was evident that any injury on the plats fumigated with sulphur dioxide must certainly be due to the gas.

However, the question arose as to whether or not the plants were rendered especially susceptible to the gas, owing to the change in the temperature and humidity brought about by placing the cabinet over the grain. It is true that during the long-time fumigations, with the long cabinets first used, the temperature at the far end of the cabinet was invariably higher than at the inlet. On hot sunny days, the temperature was as much as 14° C. higher at this point than at the intake. There was frequently a considerable difference in the relative humidity; sometimes higher, at other times lower at the far end than at the inlet end. However, the worst injury was

A. FUMIGATION CABINET.

B. GENERAL VIEW OF EXPERIMENTAL FIELD AT VALLEJO.

invariably found in the first part of the plat, in fact, directly in front of the delivery pipe, where the temperature and humidity were that of the air being blown in, and where no abnormal change took place.

In order to determine the effect of temperature and humidity on the susceptibility of the plants, fumigations were conducted under various conditions. It was found that the humidity was of great importance in affecting the susceptibility of the plants; of far greater importance than the change of temperature or of the influence of sunlight and shade.

A fumigation lasting an hour or longer was not considered to be comparable to actual conditions existing in a smelter-smoke zone, certainly not in the Selby smoke zone. In our field analytical work in the Selby district it was found that a concentration as high as 1 part sulphur dioxide per million of air might exist for a considerable period. On a few rare occasions a concentration of 2 parts was found to persist about 20 minutes at a time. Concentrations above that amount were found only at long intervals and for only a few minutes at a time.

Thus it was decided to carry on some fumigations, each of only 10 or 15 minutes' duration, but repeated frequently. Other fumigations were carried out in 5-minute doses. Still others received only 2-minute doses. These short-period fumigations eliminated to a great extent, if not completely, the temperature and humidity changes during the fumigations. As is shown later, the temperature and humidity changes at the far end of the cabinets during the 5-minute fumigations were very slight. The 2-minute fumigations were conducted under shorter cabinets and the air was blown in at both ends, thus eliminating any changes whatever in temperature and humidity.

The fact that the barley field at Vallejo was rather poorly cultivated and planted gave rise to the question concerning the influence of poor cultivation upon the susceptibility of the plants to sulphur dioxide. It was thought possible that the barley was rendered especially susceptible by reason of the poor cultivation. Thus, it was considered desirable to carry on similar experiments on barley that had been well planted in a well-cultivated field, to determine whether the results would check those obtained at Vallejo. By courtesy of the dean, H. E. Van Norman, and associates at the university farm at Davis, we were able to conduct a series of experiments there, checking the work at Vallejo. Many experiments were carried on at Davis in the same manner as at Vallejo, and practically the same results were obtained. Thus, it is evident that the factor of poor cultivation did not materially influence the results.

When the long 610-cm. cabinets were used it was found by analysis that the concentration of the sulphur dioxide at the far end of the

cabinets was considerably lower than at the inlet. No air was allowed to leak into the cabinet. In fact, the air inside the cabinet was usually leaking out around cracks, etc. Thus, there could be no dilution with sulphur dioxide free air. The decrease in concentration must, therefore, have been due to absorption of the sulphur dioxide by the vegetation, soil, and celluloid. That this absorption by vegetation and soil is extremely rapid was proven in special experiments in the field and in the laboratory.

The rate of decrease in concentration was not constant, but was dependent upon the moisture present in the soil or on the foliage, also upon the height and stage of growth of the plants. In one fumigation, when the soil was wet and the plants had drops of water standing on them, 75 per cent of the sulphur dioxide was absorbed in the passage of the air through the cabinets.

At Davis it was found that there was an absorption of about 40 per cent of the sulphur dioxide between the front and back of the cabinet when the ground and vegetation was quite dry and the barley was about 46 cm. high. The fan was discharging into the cabinet about 5.1 cubic meters per minute, containing 25.5 c. c. or 0.013 gram of SO_2 per cubic meter. Of all the analyses made in the long cabinets both at Vallejo and Davis the average concentration at the far end was found to be about 66 per cent of the concentration at the inlet. This explains why on many plats less damage was found at the far end than at the inlet end.

In order to maintain more nearly the same concentration throughout the length of the cabinet, it was necessary to increase the volume discharged into the cabinet or else decrease the length or volume of the cabinet. For this purpose a larger fan was obtained for the Vallejo work. This object was accomplished also by using a fan at both ends of the cabinet and allowing the air to escape through the center. To an even greater degree this was accomplished by reducing the length of the cabinet to 300 cm. and blowing the mixture in at both ends. In this last scheme of fumigation the foliage was kept in motion throughout the whole plat by the force of the wind currents. This last method eliminated any criticism arising from the fact that in the long cabinets, with air being blown in at only one end, the foliage at the far end was in a relatively quiet atmosphere, and thus subjected to an abnormal condition.

At Davis the larger fan did not deliver the volume desired, due to the drop in voltage over a longer and smaller transmission line. Thus we found a greater difference in the concentration at the two ends of the cabinet and, as a result, a great difference in the injury at the two ends.

DETERMINATION OF THE YIELD OF THE PLATS.

The determination of the comparative yield of the fumigated and checked plats was one of the chief objects in this work. At Vallejo, due to the uneven planting and the rough character of the soil, the number of plants in the plats was variable. At both Davis and Vallejo, due to variations in the moisture content of the soil and other natural causes, the height of the plants in the plats also varied. Thus, it would be difficult and lead to wrong conclusions to base the comparison of the yields of the plats upon the area unit.

Our observations during the work showed that no plants were killed, even under the most severe treatment given, and that the normal amount of stooling appeared to take place in practically all cases. Thus, the logical basis for comparing the yields is the yield per stalk or head.

In the comparison of the yields from these experimental plats the total yields are compared on the basis of the "total weight of heads and straw" per unit head. The grain yield is based on the average weight of the grain thrashed from each good head. As will be noted, the percentage of good heads—that is, heads free from mold—was greater in the fumigated than in the unfumigated plats. In some of the fumigated plats the percentage of good heads was much greater than in the check plats, which indicated that the sulphur dioxide served to kill the mold. As a supplementary note in many of the tables in which the yields have been compared the comparison has been made of the weight of "grain" per unit "total head."

The barley in a strip (approximately 61 cm. by 461 or 273 cm.) through the center of the plats was cut by hand. The barley was cut close to the ground, tied in bundles properly tagged, and placed inside coarse-mesh cotton bags and allowed to dry several days. The total weight of each sample was then determined and the number of stalks or heads was counted. The moldy heads were discarded during the counting, but included in the total count. The good heads were then thrashed carefully by hand and the chaff winnowed. The weight of the grain in each sample was then carefully determined. Then 100 kernels of grain from each sample were counted out and the weight of this number carefully determined. Thus, the following data were determined by counting and weighing: (1) Total weight of straw and heads; (2) total number of heads; (3) number of good heads—that is, heads free from mold; (4) weight of grain; and (5) weight of 100 kernels.

From these data the following details could be calculated for the purpose of comparison: (1) Total weight of straw and heads per unit head; (2) weight of grain per unit head; (3) number of kernels

per head; (4) percentage of good heads to the total; and (5) relative yield based on values 1 and 2.

The check plats were in many cases fumigated, for the same length of time and under the same conditions as the plats with which they were compared, with the atmosphere of the field which contained no determinable amount of sulphur dioxide. At no time during the fumigation work did the check plats show any visible injury due to being under the cabinets. There was not even an increase in the amount of bacterial disease in the checks fumigated under cabinets above those that were never fumigated at all.

Samples were taken through the center of the plat to eliminate any foliage or heads in the outside rows that might have been bruised by the cabinet, etc.

In the discussion and notes concerning the injury to the barley two types of injury will be referred to, as follows: (1) The mottled type, and (2) the "concentrated" or kill-back type.

Mottled type of bleach.—This type of injury was first observed on the short-period fumigations with the very dilute gas. The primary appearance of this type of injury is as illustrated in Plate XII, *C*, and Plate XV.

The developed mottled type of bleach.—As the first "mottled" type of bleach develops it becomes more like the bleach as shown in the leaves held up for inspection in Plate XVI, *A*.

The "concentrated" or "kill-back" type of bleach.—This type of bleach appeared wherever the barley had had a very severe dose. In general the barley is bleached white continuously back from the tips. When the leaf has received this type of bleach at the end it usually has considerable bleach of the "developed mottled" type closer to the stem.

FUMIGATION EXPERIMENTS AT VALLEJO.

The work at Vallejo was started on March 20, 1914, when the plants were about 7.5 to 10 cm. high and had from two to four leaves stooled out.

The part of the field in which these experiments were made had been plowed in December. A moldboard plow was used. It was seeded early in March with a broadcast seeder and the seeding followed by a rough harrowing.

The ground was so rough and so many bumps were present that it was difficult to place the cabinets squarely on the ground. In fact, in laying out most of the plats it was necessary to use a hoe or small shovel to remove lumps or fill in depressions so that the cabinet would sit squarely on the ground.

GRADUATIONS OF SULPHUR DIOXIDE INJURY FROM "INCIPIENT MOTTLED" TO "CONCENTRATED" OR "KILL-BACK" TYPES.

A. DEVELOPED "MOTTLED" TYPE OF BLEACH.

B. GRAIN IN PLAT 59, MAY 2, 1914, AFTER SECOND FUMIGATION.

C. CHARACTER OF BLEACH ON PLATS 33, 34, AND 35, APRIL 27, 1914, AFTER EIGHTY 5-MINUTE FUMIGATIONS.

A. DEVELOPED "MOTTLED" TYPE OF BLEACH.

B. GRAIN IN PLAT 59, MAY 2, 1914, AFTER SECOND FUMIGATION.

C. CHARACTER OF BLEACH ON PLATS 33, 34, AND 35, APRIL 27, 1914, AFTER EIGHTY 5-MINUTE FUMIGATIONS.

The plats were laid out in rows, from 60 to 120 cm. being allowed between each plat. Plate XIV, *B*, gives a general view of experimental field at Vallejo.

The experimental work at this field was planned and is here discussed under the following classification:

Series 1.—Experiments to determine the effect of one or two comparatively strong fumigations made (*a*) during early stages of growth, while the plants were less than 15 cm. high; (*b*) during the time between that included in *a* and the "heading-out" stage; (*c*) during the period when the grain was developing, while the grain was in the "milk" or "dough" stages.

Series 2.—Experiments to determine the effect of fumigating for 10-minute periods for an average of once per day during the entire growing season with definite concentrations of sulphur dioxide.

Series 3.—Experiments to determine the effect of three fumigations per day, each of five minutes' duration, during the entire growing season, with definite concentrations of sulphur dioxide.

Series 4.—Experiments to determine the effect of a considerable number of 5-minute fumigations after the plants had stooled out.

Series 5.—Experiments to determine the effect of a considerable number of 2-minute fumigations while the grain was forming in the head, "in the milk."

Series 6.—Experiments to determine the effect of fumigations with very dilute gas for comparatively long periods daily during the whole growing season.

Series 7.—Experiments expressly to determine the possible existence of "invisible injury."

Series 8.—Miscellaneous experiments to determine the influence of humidity, sunlight, and shade upon the susceptibility of the plants to sulphur dioxide.

Series 9.—Experiments to determine the relative injurious effect of sulphur-dioxide gas and sulphur-trioxide fume and vapor.

Series 10.—Special experiments.

EXPERIMENTS IN SERIES 1*a*.

Series 1*a* included the plats that received either one or two strong fumigations with sulphur dioxide during the early stages of growth—that is, when the plants were less than 15 cm. high.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

VISIBLE EFFECTS OF FUMIGATIONS.

A continuous fumigation for an hour with 3 or more parts of SO_2 per million parts of air by volume (0.0080 gram of SO_2 per cubic meter) on barley when the plants were less than 15 cm. high caused visible bleaching. With concentrations of over 5 parts of SO_2 per million, the injury was great, more than two-thirds of the foliage being bleached. The injury produced was principally the "concentrated" or "kill-back" type. Severe bleaching was also produced by repeated long-time fumigations with a concentration as low as 1 part of SO_2 per million. The bleach developed most rapidly in sunlight.

EFFECT OF SINGLE FUMIGATIONS ON YIELD.

One severe bleaching of the plants during this period of growth did not cause an appreciable decrease in the yield. The total weight of crop cut from the fumigated plats averaged within 1 per cent of the yield from the check plats. The weight of the "grain" itself averaged only 2 per cent less than that of the check plats.

EFFECT OF A DOUBLE FUMIGATION ON YIELD.

In the two treated plats a decrease of about 10 per cent was found in the "total weight" of each crop. One plat showed no decrease in the "grain" yield, the other showed 20 per cent decrease. The first plat received its "kill-back" fumigation about eight days earlier than did the second. Thus it had a better chance to recover. Little rain fell after the last of these fumigations, and the soil dried up rapidly.

In discussing the recovery of crops from severe injury caused by sulphur dioxide, it must be remembered that the nature of the season is a factor of great influence on the results. In a season when there is plenty of rain plants injured in the early stages of growth would have a better chance to recover and give a normal yield than in a season of drought. The winter season at Vallejo was a wet one and the soil was well supplied with moisture at the beginning of the growing season. However, after April 1 there was little precipitation, and the soil dried up rapidly and cracked badly. Thus the conditions at the Vallejo field were not especially favorable for the recovery of the plants from injury.

Summary of results of experiments in series 1a, Vallejo.

[Fumigations made when the barley plants were less than 15 cm. high.]

SINGLE SEVERE BLEACH.

Plat No.	Concentration of SO_2.		Length of fumigation.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—		Remarks.
	Parts per million.	Grams per cubic meter.			Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.	
			Hours.		*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*	
Check..	.....	.....	1	202	2.54	1.17	3.68	32	100	100	Of the total number of heads from the check plat, ony 89 per cent were free from mold. No. 8 and No. 9 had 90 per cent and 94 per cent good heads out of the total. Basing the relative grain yield of No. 8 and its check on the weight per unit total head, the plat No. 8 yielded 103 per cent of the check's yield.
1.....	10	0.0262	1	226	2.47	1.13	3.90	29	97	96	
2.....	5	.0131	1	199	2.50	1.16	3.64	32	98	99	
Check..	0	0	1	214	2.51	1.12	3.61	31	100	100	
3.....	4	.0106	1	192	2.47	1.21	3.66	33	98	108	
Check..	0	0	1	195	2.44	1.33	3.92	34	100	100	
6.....	5	.0131	1	188	2.37	1.19	4.27	28	97	90	
Check..	0	0	43	288	2.88	1.33	4.28	31	100	100	
8.....	2	.0052	12	248	2.94	1.30	3.67	36	102	98	
9.....	1	.0026	43	320	2.85	1.30	4.05	32	99	98	

REPEATED SEVERE BLEACHES.

Check..	0	0	[a]2	200	2.54	1.17	3.68	32	100	100	If the comparative grain yields of No. 22 and its check were based on the weight of grain per total heads, the yield from No. 22 would be 88 per cent of the check.
11.....	20	.0524	1	.....	.....	.....	.....	.....	.....	.....	
	10	.0262	1	207	2.29	1.19	4.05	29	90	102	
Check..	.....	.....	.....	224	2.95	1.59	4.21	38	100	100	
22.....	10	.0262	1	.....	.....	.....	.....	.....	.....	.....	
			1	238	2.56	1.29	4.14	31	87	81	

[a] Two 1-hour fumigations.

PLAT 1.

Approximate average height of plants, 10 centimeters.

Date of fumigation, March 20, 1914.

Time of fumigation, 1 hour (12.45 to 1.45 p. m.).

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 38 c. c. per minute.

Calculated concentration, 10 parts SO_2 per million by volume (0.0262 gram per cubic meter).

Concentration found by analysis—At inlet, 9.8 parts SO_2 per million by volume; at outlet, 6.2 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 26° C.; average at outlet, 36° C.

Cabinet relative humidity—average at inlet, 52 per cent; average at outlet, 40 per cent.

Notes.

Sunlight. Before the end of the hour the leaves had wilted down and become faded green. They did not begin to bleach until after the hood was removed. By 5 p. m, about 90 per cent of the leaves had bleached to the "concentrated" or "kill-back" type.

March 21.—All blades affected, oldest leaves more so than the youngest. Total percentage of leaf area bleached about 90 per cent. Plants at back end of the hood not so badly affected as in the front, near the inlet.

March 28.—New shoots of barley coming up. The bleached leaves not recovering where burned close to the ground, but where tops only were bleached the leaves continue to grow. Bleached foliage now white.

March 30.—New shoots growing very rapidly after rain of March 29 and 30.

April 3.—Few bleached leaves showing. New green shoots predominate. Grain not so far advanced as corresponding check plat 1*a*.

April 6.—Practically all signs of bleached leaves disappeared. All foliage green, but not so high as in check plat.

After April 12 no trace of any previous sulphur dioxide injury was visible. The plants near the front of the plat were smaller and the stand was thinner than in the back or in the check plat. It was evident that this thinner stand was due to poor soil conditions and poor planting rather than to the previous bleaching. During May the leaves began to turn yellow, partly due to bacterial disease and partly to maturity, similar to the rest of the field. The plat and its check were cut on June 26. Area sampled, 2.8 square meters.

PLAT 2.

Approximate average height of plants, 10 cm.

Date of fumigation, March 20, 1914.

Time of fumigation, one hour (10 to 11 a. m.).

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 19 c. c. per minute.

Calculated concentration, 5 parts SO_2 per million by volume (0.0131 gram per cubic meter).

Concentration found by analysis—at inlet, 4.8 parts SO_2 per million by volume; at outlet, 3.2 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 24° C.; average at outlet, 32° C.

Cabinet relative humidity—average at inlet, 52 per cent; average at outlet, 56 per cent.

Notes.

Partly cloudy. At the end of hour's fumigation the leaves were generally wilted and slightly faded. In the afternoon the leaves began to bleach.

March 21.—The ends of all blades were bleached yellowish white, the bleach extending continuously back from the tips. Over part of the broad leaves there is a slight white mottling. Area bleached equals about 50 per cent of the total.

March 28.—New green foliage appearing as new shoots.

March 30.—The new shoots are growing rapidly. The old bleached leaves are now quite white and have not recovered to any extent.

April 3.—The old bleached leaves are lying on the ground. The new foliage predominates.

April 6.—Practically all signs of bleached leaves have disappeared. No bleach on the leaves now standing.

After April 12 there were no signs of the sulphur dioxide bleach. The plants appeared to be perfectly normal in size and in general appearance.

During May the yellow rust appeared on the leaves as in the rest of the field.

The plat was cut on June 26.

Area sampled, 2.8 square meters.

PLAT 3.

Approximate average height of plants, 10 cm.

Date of fumigation, March 20, 1914.

Time of fumigation, one hour (11.30 a. m. to 12.30 p. m.).

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 15.2 c. c. per minute.

Calculated concentration, 4 parts SO_2 per million by volume (0.0104 gram per cubic meter).

Concentration found by analysis—at inlet, 4.1 parts SO_2 per million by volume; at outlet, parts SO_2 per million by volume not determined.

Cabinet temperature—average at inlet, 26° C.; average at outlet, 34° C.

Cabinet relative humidity—average at inlet, 48 per cent; average at outlet, 40 per cent.

Notes.

Sunlight. At the end of the hour's fumigation the leaves began to show signs of wilting and the faded green color was noted. By 5 p. m. the bleaching became apparent.

March 21.—The ends of the leaves are practically all bleached to a nearly white color, although many are yellowish white. The bleaching extends uniformly back from the tip. Only slight "mottling" appears. About 30 to 40 per cent of the total area bleached.

March 28.—Very rapid growth of new shoots noted. The old leaves also growing, although the bleached tips appear to be dead.

March 30.—Rapid growth after rains of March 29 and 30.

April 3.—With the exception of a few white tips practically all the leaves standing are green. Very few signs of old bleach remain.

April 6.—Plat appears green except for a few dead leaves around the base of the plant.

April 12.—After this date there were no traces of the old bleach. The plants appear normal, although the stand is thin. About the same as the checks in general appearance throughout the rest of the growing season.

Plat cut June 26.

Area sampled, 2.8 square meters.

PLAT 4.

Approximate average height of plants, 10 cm.

Date of fumigation, March 21 and 22, 1914.

Time of fumigation, March 21, 9.50 to 10.50 a. m.; March 22, 11.30 a. m. to 12.30 p. m.—total, two hours.

Volume of air through cabinet, 3.5 cubic meters per minute.

Volume of SO_2 added to air, 10.5 c. c. per minute.

Calculated concentration, 3.0 parts SO_2 per million by volume, 0.0078 gram per cubic meter.

Concentration found by analysis—at inlet, 3.0 parts SO_2 per million by volume; at outlet, 2.3 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 20° C.; average at outlet, 25° C.

Cabinet relative humidity—average at inlet, 55 per cent; average at outlet, 59 per cent.

Notes.

Partly cloudy. After first fumigation the leaves began to turn a darker, faded green and to droop slightly.

March 22.—In the morning many of the leaves were slightly "mottled" or bleached. After the second fumigation the drooping and discoloration of the leaves was much more noticeable. By 5 p. m. the bleeching of the leaves was very evident.

March 23.—About 20 per cent of the total foliage is bleached or "mottled" worse on the first and second leaves than on others.

March 30.—New growth of foliage is rapidly obliterating the old bleached leaves.

April 6.—All signs of old bleach gone.

April 12.—After this date the growth of the plants appeared normal, but the stand was very short and thin, due to the poor soil condition.

This plat was so uneven and the ground was so badly cracked in May and June that it was not cut for quantitative results.

PLAT 5.

Approximate average height of plants, 9 to 10 cm.

Date of fumigation, March 21 and 22, 1914.

Time of fumigation, 2 hours—March 21, 11 a. m. to 12 m.; March 22, 2.15 to 3.15 p. m.

Volume of air through cabinet, 3.5 cubic meters per minute.

Volume of SO_2 added to air, 7 c. c. per minute.

Calculated concentration, 2 parts SO_2 per million by volume, 0.0052 gram per cubic meter.

Concentration found by analysis—at inlet, 2.2 parts SO_2 per million by volume; at outlet, 1.6 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 20° C.; average at outlet, 27° C.

Cabinet relative humidity—average at inlet, 59 per cent; average at outlet, 63 per cent.

Notes.

Cloudy. At the end of the first fumigation there was a slight drooping and darkening of a few leaves. No bleaching appeared before evening.

March 22.—No bleach showed in morning. After second fumigation the drooping was more pronounced.

March 23.—The first half shows distinct bleaching with some "mottling" on leaves in the back end of the plat. About 10 per cent of area bleached.

March 30.—Most signs of bleaching have disappeared, except for a few leaf tips.

April 6.—No signs of first bleaching were present. From this date on the appearance of the plat was perfectly normal. The stand was very thin and the plants were short

due to poor soil and cultivation. As the soil in this plat became badly cracked due to dry spell in May, the yield was abnormally low and the plat was not cut for quantitative results.

PLAT 6.

Approximate average height of plants, 8 to 12 cm.

Date of fumigation, March 23, 1914.

Time of fumigation, one hour (10.30 to 11.30 a. m.).

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 19 c. c. per minute.

Calculated concentration, 5 parts SO_2 per million by volume (0. 131 gram per cubic meter).

Concentration found by analysis—at inlet, 4.9 parts SO_2 per million by volume; at outlet, 4 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 21° C.; average at outlet, 24° C.

Cabinet relative humidity—average at inlet, 60 per cent; average at outlet, 68 per cent.

Notes.

Cloudy. Due to the moist condition of the soil, the relative humidity at the far end of the cabinet during the fumigation was higher than outside. The plants began to droop and darken during the fumigation time. Bleaching did not begin to show until later in the afternoon. Plat 6*a* received the same treatment except no sulphur dioxide was added.

March 24.—Early in the morning the leaves were not changed greatly in appearance from the evening of the 23d. By noon, however, the sun came out bright and the leaves bleached rapidly. At 5 p. m., in the front part of the plat, the leaves were practically 70 to 80 per cent bleached, the bleached area extending solidly back from the tips. In the back part of the plat the leaves were not so badly bleached. It is to be noted that the damage to the leaves in plat 6 was apparently greater than in plat 2, which received the same treatment, but under lower humidity conditions.

March 30.—The rains on March 29 and 30 have hastened the rapid growth of the new foliage in the plat. New shoots are coming up from every plant, which fact bears out our observations on the other plats previously fumigated, that even by very severe injury no plants are actually killed.

April 6.—Little evidence of the bleach now remains. Some of the leaves show bleached tips.

April 12.—No evidence of bleach in any part of the plat. Plants are somewhat shorter than in plat 6*a*. Plants in both 6 and 6*a* slightly shorter than plants in other parts of the field (see Pl. XVII, *A*).

From this time on the two plats were alike and normal in every way. The grain on the two plats, as the grain in the immediate vicinity outside the plats, was slow in ripening. Although the greater parts of the plats were ready for harvest on June 26, it was necessary to wait until July 2 before harvesting plats 6 or 6*a*.

Area sampled, 2.8 square meters.

PLAT 8.

Approximate height of plants, 10 to 15 cm.

Date of fumigations, March 20, 21, and 22.

Time of fumigations, 4 hours each day—12 hours total.

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 7.6 c. c. per minute.

Calculated concentration, 2 parts SO_2 per million by volume (0.0052 gram per cubic meter).

Concentration found by analysis—at inlet, 2.1 parts SO_2 per million by volume; at outlet, 1.6 parts SO_2 per million by volume.

Cabinet temperature—average at inlet, 25° C.; average at outlet, 32° C.

Cabinet relative humidity—average at inlet, 52 per cent; average at outlet, 57 per cent.

Notes.

Sunny. At end of the first four hour's fumigation a few of the leaves were drooping slightly.

March 21.—Slight bleaching evident before the second fumigation. At the end of second fumigation the leaves are drooping slightly more than in the morning. The tips of the leaves are slightly faded and appear to be injured.

March 22.—Bleaching evident all over the plat in morning. At the end of the third fumigation the bleached area is increased. Probably 25 to 30 per cent of total leaf area affected. Fumigations are stopped to let damage develop.

March 24.—The injury to the leaves very general. Bleach probably fully developed and covers about 30 per cent of the leaf area. General solid "concentrated" type bleach back from tip, but some "mottling" shows.

March 30.—The barley is recovering very rapidly due to the rains of March 29 and 30. The portions of leaves affected apparently not reviving, but the new growth is obliterating the bleached areas.

April 3.—Except for slight bleached area on the tips of a few leaves the plants appear perfectly normal and similar to those in check plat 10.

April 6.—The plants in this plat appear perfectly normal and are as high as in the average check plat. No signs of previous damage now show. Plants somewhat thinner stand in front of plat than in back.

After April 6 the development of the plants in this plat was perfectly normal. The plants were as high though not so thick as in the check plat 10 or the fumigated plat 9. The plants in Nos. 8, 9, and 10 were higher than those in Nos. 1, 2, 3, 4, and 5. The grain ripened at about the same time as No. 9 and No. 10 and was cut on June 26.

Area sampled, 2.8 square meters.

PLAT 9.

Approximate height of plants, 10 to 15 cm.

Date of fumigation, March 20 to 25, 1914.

Time of fumigation, 43 hours (5 7-hour periods and 1 8-hour period).

Volume of air through cabinet, 3.8 cubic meters per minute.

Volume of SO_2 added to air, 3.8 c. c. per minute.

Calculated concentration, 1 part SO_2 per million by volume (0.0026 gram per cubic meter).

Concentration found by analysis—at inlet, 1 part SO_2 per million by volume; at outlet, 0.6 part SO_2 per million by volume.

Cabinet temperature—average at inlet, 27° C.; average at outlet, 35° C. (maximum 40° C.).

Cabinet relative humidity—average at inlet, 55 per cent; average at outlet, 60 per cent.

A. PLANTS IN PLATS 6 AND 6*a* ON APRIL 15, 1914.

B. GRAIN IN PLAT 16 ON APRIL 27, 1914.

Notes.

March 20.—No signs of bleaching or drooping at end of first six-hour fumigation.

March 21.—Very slight "mottling" appeared at end of second fumigation; that is, after 14 hours of fumigation.

March 22.—Increase in number of "mottled" leaves more general near the front of the plat.

March 23.—Appearance of leaves about the same as noted on March 22.

March 24.—Slight increase in extent of "mottled" area near front of plat—about 5 to 10 per cent of area "mottled" in front. Very slight in back.

March 25.—The "mottling" is gradually changing to the "developed mottle" and "concentrated" bleach extending back from tips and between the veins. The back parts of the plat still show only slight effects. Fumigations ceased.

March 30.—White tips still evident. Plants are growing very rapidly, after the rains of March 29 and 30, and the percentage of total area that is bleached is decidedly decreased.

April 3.—Very few leaves showing the bleach now. Plants about normal in size as compared with those in plat 10.

April 6.—Practically all signs of previous bleach have disappeared. The plants look to be the same in size and in every way with those of plat 10.

After April 12 the plat appeared almost the same in every way as plat 10, though the stand was probably thicker in plat 9 than in plat 10. The grain in plat 9 ripened at the same time as that in plat 10 and was cut on the same day, June 26.

Area sampled was 2.8 square meters.

PLAT 11.

Approximate height of plants, 7.5 to 10 cm., first fumigation; 10 to 13 cm., second fumigation.

Date of fumigation, first, March 20, 1914; second, April 2, 1914.

Time of fumigation, one hour each time.

Volume of air through cabinet, 3.5 cubic meters per minute.

Volume of SO_2 added to air, first fumigation, 70 c. c. per minute; second fumigation, 35 c. c. per minute.

Calculated concentration, first fumigation, 20 parts SO_2 per million by volume (0.0524 gram per cubic meter); second fumigation, 10 parts SO_2 per million by volume (0.0262 gram per cubic meter).

Concentration found by analysis, first fumigation, at inlet, 18.5 parts SO_2 per million by volume; second fumigation, at inlet, 10.2 parts SO_2 per million by volume; first fumigation, at outlet, 12 parts SO_2 per million by volume; second fumigation, at outlet, 7.8 parts SO_2 per million by volume.

Cabinet temperature, at inlet, 26° C.

Notes.

March 20.—The object of this fumigation was to bleach the leaves completely. The leaves began to wilt and fade in about 15 minutes. At the end of an hour all leaves lying flat on the ground and bleaching very rapidly.

March 21.—Practically all leaves injured back to the ground. In some cases the leaves retain their faded green coloring. In all cases injury extends solidly from the tips. No "mottling." Injury worse at the front than at the back. Wild turnips in the plat also very severely injured.

March 30.—The plants are reviving very rapidly in the rains. No indication of any plant having been killed outright, for shoots are coming up from every one of the original plants. Of course the plants are behind the others in growth.

April 2.—Tips of many leaves still show signs of first bleach. Plants are decidedly smaller than in the check plats. Plants seem to have outgrown the original bleach considerably. On this day the plat was subjected to a second fumigation of one hour with a concentration of 10 parts SO_2 per million. At the end of the hour's fumigation the plants are again wilted and faded.

April 3.—Leaves of all plants bleached again. The plants look about as did the plants in plat 1, after the fumigation of March 20. The fumigation means practically the same as cutting the grain back to the ground.

April 6.—From every plat green shoots are coming up. No plants killed. New shoots growing very rapidly, but much shorter than the check.

April 20.—On a few leaves the tips were still white, but practically all signs of previous damage are eliminated. The plants are much shorter and seemed to be thinner than are those of the check plat.

May 11.—Plants are still shorter and not so far advanced as those in the check. Appear to be almost two weeks behind.

May 21.—Plants in plat 11 shorter than in check, but the heads are filling out. Will probably mature the grain soon after the check.

May 29.—Grain in plat 11 is greener than in check.

June 26.—The grain in plat 11 was sufficiently ripe to cut. In the check plat the grain had been equally ripe for several days. Thus the setback was not greater than one week at the end. Check plat also cut on June 26.

Areas sampled, 2.8 square meters.

PLAT 22.

Approximate height of plants, 10 to 15 cm.

Date of fumigation, March 28 to April 10, 1914.

Time of fumigation, one hour each time.

Volume of air through cabinet, 3.5 cubic meters per minute.

Volume of SO_2 added to air, 35 c. c.

Calculated concentration, 10 parts SO_2 per million by volume (0.0262 gram per cubic meter).

Concentration found by analysis, not made.

Cabinet temperature, average at inlet, 20° C.

Cabinet relative humidity, average at inlet, 58 per cent.

Notes.

March 28.—This fumigation was made during cloudy conditions, and, although the plants wilted down and faded somewhat, the bleach did not appear during the day.

March 30.—Not until the sun came out during the afternoon to-day did the bleach fully develop. Now the leaves appear bleached back solidly from the tips. No "mottling" showing. Most leaves are lying down on the ground. Injury done to about 90 per cent of the total foliage. The leaves that were wet during the fumigation are twisted and white.

April 2.—Green shoots coming up. No plants killed.

April 6.—Plants growing very rapidly. Marks of old injury still evident, though proportion to total foliage is less than 20 per cent.

April 11.—Morning. Except for a few tips the leaves are quite free from the marks of the old injury. Fumigated this date with 10 parts SO_2 per million parts of air for

one hour. The leaves wilted down, faded, and bleached in a short time. Practically all the "kill-back" type bleach.

April 20.—Plants are recovering very rapidly. Much of the bleach caused by the fumigation of the 11th still visible. New foliage in good green condition.

May 1.—Plants in plat 22 are practically all free from old injury and the grain developing normally. Plants are much shorter than the plants in the check plat.

May 11.—Plants are shorter than the check plats, but are heading out in the same manner as the check. No signs of former injury to leaves.

May 29.—It is now difficult to distinguish between the fumigated plat 22 and the control plat 22*a*, for both are about the same in height and general appearance.

June 15.—It is evident that the grain in plat 22 will ripen a few days later than in the check plat. Both are somewhat behind the plats in the other parts of the field.

June 26.—Neither plat 22 nor 22*a* is quite ready for harvesting. Some of the heads are still green.

July 2.—Both plat 22 and the check plat harvested.

Area sampled, 1.67 square meters.

Results of experiments in series 1a, Vallejo.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	2.8	1,415	558	508	91	597
1	2.8	1,560	632	574	91	647
2	2.8	1,415	566	490	87	567
Check	2.8	1,502	599	547	91	615
3	2.8	1,332	538	496	92	601
Check	2.8	1,332	546	454	83	606
6	2.8	1,246	526	444	84	530
Check	2.8	2,322	806	716	89	955
8	2.8	2,041	694	654	94	852
9	2.8	2,549	895	803	90	1,042
Check	2.8	1,415	558	508	91	597
11	2.8	1,332	581	512	88	608
Check	1.67	1,105	375	324	86	515
22	1.67	1,018	398	371	93	478

EXPERIMENTS IN SERIES 1b.

In this series are the plats that received from one to three strong fumigations of sulphur dioxide between the time the plants were 15 cm. high and the time when the grain was heading out. In this subdivision are included only those plats fumigated during this period for the purpose of obtaining quantitative results on the yields. The plats fumigated under various humidity conditions, etc., to determine only the influence of humidity on the susceptibility of the plants to sulphur dioxide at this stage of growth, are discussed elsewhere. Thus the plats in this series are plat 46 and its check, and plats 58, 59, 60, and 61, and their check plat.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

VISIBLE EFFECTS OF FUMIGATIONS.

As a result of an hour's fumigation of 5 parts SO_2 per million parts of air by volume (0.013 gram SO_2 per cubic meter) the total area of the foliage bleached was greater than that produced by a similar fumigation during the earlier stage of growth. The proportion of this bleached area to the total foliage, however, was less. Repeated fumigations increased the extent of the bleached surfaces to more than 50 per cent of the total. The total area ultimately bleached was approximately the same, whether the fumigations were given in one or two long-time doses or a greater number of shorter doses within a few days. The injury was extremely severe in all cases.

EFFECT ON THE YIELD.

The average decrease in the total weight of "straw and heads" from the fumigated plats compared with the checks was approximately 14 per cent.

The average decrease in the yield of the "grain" was 10 per cent.

The effect upon the yield was greater than that produced by a severe bleach in the earlier stages of growth.

Summary of results of experiments in series 1b, Vallejo.

[Fumigations made when the barley plants were more than 15 cm. high, up to time of heading out—fumigations caused severe injury.]

Plat No.	Concentration of SO_2.		Length of each fumigation.	Number of fumigations.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.				Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
			Hours.			*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
Check					199	3.12	1.31	3.74	35	100	100
46	5	0.0131	1	3	210	2.41	1.35	4.42	31	77	103
Check					248	3.04	1.55	4.46	35	100	100
58	5	.0131	1	2	283	2.82	1.29	3.63	36	93	83
			Minutes.								
60	5	.0131	5	24	201	2.61	1.23	3.47	35	86	79
61	5	.0131	2	60	195	2.71	1.50	4.12	36	89	97

NOTE.—Average yield of fumigated plats, based on total weight, 86.2 per cent; based on weight of grain per good head, 90.5 per cent.

PLAT 46.

This plat was 120 by 300 cm. in area. It was fumigated for one hour on April 18, 20, and 21, 1914, with 5 parts SO_2 per million parts of air by volume (0.013 gram SO_2 per cubic meter). After the first fumigation the front of the plat was very badly bleached. About 40 to 50 per cent of the total area of the leaves had the "concentrated"

type of bleach extending back from the tips. The far end had more of the "mottled" type of injury. In the fumigations of April 20 and 21 the mixture was blown in at the opposite end. Thus the bleach was equalized throughout the length of the plat. About 50 per cent of the foliage throughout the whole plat was badly bleached, as shown in Plate XI, *B*, and Plate XVIII, *A*.

The bleached leaves of this plat were in evidence for a long time. In fact, to the very end of the season the signs of the injury could be found readily. However, the plants continued to develop. The new leaves came out quickly and the heads developed normally. By the middle of May, except for the abnormal number of dried-up basal leaves, the plants appeared to be developing in the ordinary manner. The height of the grain at the end of the season was less than that in the check plat. The heads, however, seemed as large and as well developed as in the check.

This plat was cut on June 26, as was also the check. The area cut was 61 by 457 cm., or 2.79 square meters, through the center of the plat. The check plat received no fumigation.

PLATS 58, 59, 60, AND 61.

The area of these plats was each 121 by 305 cm., or 3.7 square meters. While these plats were being fumigated, the air and sulphur dioxide mixture was blown in at both ends of the cabinet and allowed to escape through the center at the top. The object in fumigating in this manner was to keep the air in complete circulation through the cabinet and to keep the temperature and humidity conditions the same as those of the outside air.

The total volume blown into the cabinet per minute was 8 cubic meters. All plots were fumigated with a concentration of 5 parts SO_2 per million parts of air, by volume (0.0131 gram SO_2 per cubic meter). Each plat, however, was fumigated under different conditions and slightly different results were obtained. The plants were about 50 cm. to 60 cm. high at this time and the heads were coming out.

Plat 58.—Plat 58 received 1-hour fumigations on April 28 and May 1 in the direct sunlight with 5 parts SO_2 per million. The average temperature in the hood was 33° C., and the average humidity was 30 per cent. The average temperature of the outside air was 26° C.

Notes.

April 29.—Very severe bleach is evident throughout the plat. Older leaves are worse than the new. Sheath and head are not affected.

May 5.—About 40 per cent of all foliage is bleached and injured. Very little damage done to sheath or head. General "concentrated" type of bleach shown, although there is some "mottling" evident.

May 11.—General injury showing all over plat, except on the youngest leaves and heads.

The remains of the damage were evident until the end of the season. At end of May was most evident by abnormal number of dried up, white leaves around the base of plants.

Plat was cut June 26, 1914.

PLAT 59.

This plat was fumigated in two 1-hour periods, April 28 and May 1. During the fumigations the hood was shaded by a burlap screen. The average temperature in the hood was 24° C. and the average humidity 60 per cent. The temperature of the outside air was 24° C.

Notes.

April 28.—Very severe bleach was produced throughout the whole plat, worse than in plat 58. The older leaves were more severely damaged than the new.

May 3.—About 50 per cent of all the foliage is bleached and injured. Practically all damage was done to older leaves. The "concentrated" type of injury prevailed. Notes after May 3 are the same as on plat 58. The plat was not cut because plants were too uneven and it was not possible to get good check plat for No. 59.

PLAT 60.

Between April 28 and May 2 this plat was subjected, under shade to twenty-four 5-minute fumigations of 5 parts SO_2 per million. The time between each fumigation was at least 30 minutes, during which time the cabinet was removed from the plat. The average temperature of the mixture blown into the hood was 22° C., and the average temperature in the cabinet was 23° C. The relative humidity in the cabinet was not accurately measured, but due to the short time that the cabinet was over the plat, it was undoubtedly not much different from that of the outside air, which averaged 40 per cent.

Notes.

April 28.—After the fourth fumigation on this date a slight "mottling" appeared on some of the older leaves.

May 1.—"Mottled" areas increased and some of the "concentrated" type of bleach also appeared along the tips.

May 3.—A general bleach throughout the whole plat. Some "mottling" still remains, but the general bleach is of the "concentrated" type, extending back from the tips. The appearance now is about the same as plat 59. Notes after May 3 are similar to those applying to plat 58. The injured leaves were evident to the end of the growth, yet new leaves developed and the head matured normally after the fumigations stopped.

PLAT 61.

Between April 28 and May 3 this plat received sixty 2-minute fumigations in the shade. The total fumigation time was 120 minutes. (See Pl. XVIII, *B*.) The time between fumigations varied between 2 minutes and 20 hours. Owing to the short time that the cabinet was placed over the plat the difference in temperature between the outside and the inside of the cabinet was so slight as to be negligible, especially as the air was being blown in at both ends. Hygrodeik readings in the 2-minute intervals showed very

A. GRAIN IN PLAT 46, APRIL 26, 1914, FIVE DAYS AFTER THIRD AND LAST FUMIGATION.

B. GRAIN IN PLAT 61, MAY 7, 1914, AFTER SIXTY 2-MINUTE FUMIGATIONS OF 5 PARTS SO_2 PER MILLION PARTS OF AIR.

slight differences. Thus the average temperature, 21° C., and the average humidity, 45 per cent, may be taken as the average conditions inside the cabinet.

Notes.

April 28.—At the end of the twentieth fumigation the plants were showing marked signs of damage. First signs of damage were not noted. No fumigation on April 29.

April 30.—Very general "mottling" all over the plat and some of the "concentrated" bleach also present.

May 2 and May 3.—As the fumigations continued, the "mottled" type of injury gave place partly to the "concentrated" type, bleaching solidly back from the tips. The older leaves were most affected. Very little damage to the sheath and practically no visible damage to the head. Ultimate bleach about same as No. 59.

May 11.—Some "mottling" still appeared, though general appearances more the "concentrated" type.

The effects of the fumigations were evident until the end of the growing season, and during the latter stage caused an abnormal number of dried-up white leaves around the base of the plants. The plants in this plat were more scattered than in plats 58 or 60 or the check plat, but they were cut for quantitative purposes on June 26.

Results of experiments in Series 1b, Vallejo.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	2.79	1,728	554	481	87	632
46	2.79	1,415	586	497	85	671
Check	2.23	1,687	553	528	96	820
58	1.67	1,332	473	445	94	572
60	1.67	880	336	310	92	381
61	1.67	880	326	285	87	428

NOTE.—Basing comparative grain yield of plat 61 and check on the yield per unit total head, the yield from plat 61 was 88 per cent of the check.

EXPERIMENTS IN SERIES 1c.

In this series are the plats that received one or two strong fumigations of sulphur dioxide during the period when the grain was filling out in the head. As in series 1*b*, this subdivision includes only plats fumigated at the time for quantitative purposes and does not include plats fumigated only for the purpose of studying the susceptibility of the grain to sulphur dioxide under various conditions. Thus in this series are plats 83 and its check, 84*a*, and plats 98 and 100 and their check, 97.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

VISIBLE INJURY PRODUCED.

One-hour fumigations with 5 or 6 parts per million at this stage of growth produced very marked bleaching on all the foliage. A fumigation lasting two and one-half hours was very destructive, bleaching about 70 per cent of all the foliage. The total leaf area

bleached for any fumigation was greater at this stage than earlier in the season, though the proportion to the total was slightly less, No indications were noted that at this time the plants were materially less susceptible than earlier in the season. The beards were severely burned but no injury appeared in the heads. One plat suffered only an ordinary bleach and the other two suffered very strong bleaches.

EFFECT OF FUMIGATION ON YIELD.

Although these fumigations affected the total weight of the "straw and heads" to some extent, the greatest effect was noted in the weight of the "grain" itself. The hour fumigations of 5 parts SO_2 per million cut down the yield 20 per cent. The fumigation of 2½ hours with 6 parts SO_2 per million reduced the "grain" yield 30 per cent. The indications were that some of the kernels were actually killed and the rest were not fully developed. The fact that the plants matured grain after sustaining the severe bleach while the kernels were just beginning to form is rather astonishing. The indications from this series are that the fumigation prevented many heads from becoming moldy. Thus, although the fumigations undoubtedly reduced the size and number of the kernels in the heads, yet, by killing the mold to a certain extent, the net yield was more nearly that of the check. In a field where there was no mold this advantage of killing the mold would not be gained, and the logical basis for comparison is, therefore, the yield per unit "good head."

Summary of results of experiments in series 1c, Vallejo.

[Fumigations made when plants were headed and the grain filling out—fumigation caused severe injury.]

Plat No.	Concentration of SO_2.		Length of each fumigation.	Number of fumigations.	Average number of heads per square meter.	Weight of—			Number of kernals per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.				Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
			Hours.			*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
Check.....	0.0	0	1	1	230	3.25	1.67	4.63	36	100	100
83.....	5.5	.0142	1	1	258	2.65	1.33	4.49	30	82	80
Check.....	.....	.....	.....	.....	211	2.96	1.79	4.88	37	100	100
			Mins.								
98.....	6.0	.0156	20	1	213	2.95	1.48	4.84	31	100	83
100.....	6.0	.0156	150	1	216	2.53	1.26	4.10	31	85	70

NOTE.—Basing relative yield of grain on yield per unit "total heads," the yield was as follows: Check, 100 per cent; plat 83, 86 per cent; check, 100 per cent; plat 98, 99 per cent; plat 100, 85 per cent.

PLAT 83.

Approximate average height of plants; grain headed and in "milk."
Date of fumigation, May 18, 1914.
Time of fumigation, 1 hour.
Volume of air through cabinet, 4.2 cubic meters per minute.

Volume of SO_2 added, 23 c. c. per minute.

Calculated concentration, 5.5 parts SO_2 per million by volume (0.0144 gram per cubic meter).

Cabinet temperature, average, 24° C.

Relative humidity in cabinet, average, 40 per cent.

Notes.

May 19.—About 40 to 50 per cent of all foliage bleached and injured. All leaves injured more or less, but older leaves most. Portions of beards on the heads are burned. Except for bleached ends of beards, no visible damage done to heads. This injury was visible on the plants until the very end of the season. An abnormal number of dried basal leaves were present before the whole plant started to dry up. The fumigated plat matured at the same time as its check and was cut on June 26.

Area 121 by 305 cubic meters=3.7 square meters.

PLAT 98.

Approximate average height of plants; heads filling out; grain in "milk."

Date of fumigation, May 23, 1914.

Time of fumigation, 20 minutes.

Volume of air through cabinet, 4.2 cubic meters per minute.

Volume of SO_2 added to air, 25.2 c. c.

Calculated concentration, 6 parts SO_2 per million by volume (0.0156 gram per cubic meter).

Cabinet temperature—average at inlet, 20° C.; average at outlet, 22° C.

Cabinet relative humidity—average at inlet, 92 per cent; average at outlet, 96 per cent.

Notes.

Before fumigation it had been raining. Thus the plants were wet.

May 24.—The leaves and beards were badly injured (about 20 per cent of the area bleached). Some of the characteristic sulphur dioxide "blotches" were present where water had stood in the plants at the time of fumigation. General bleach, however, was the "concentrated" type. The heads themselves were not injured. This plat showed injury the rest of the season.

The plat was cut June 26.

Area, 3.7 square meters.

PLAT 100.

Approximate average height of plants; heads filling out; grain in "milk."

Date of fumigation, May 23, 1914.

Time of fumigation, 150 minutes.

Volume of air through cabinet, 4.2 cubic meters per minute.

Volume SO_2 added to the air, 25.2 c. c.

Calculated concentration, 6 parts SO_2 per million by volume, 0.0156 gram per cubic meter.

Cabinet temperature—average at inlet, 19° C.; average at outlet, 21° C.

Cabinet relative humidity—average at inlet, 90 per cent; average at outlet, 85 per cent.

Notes.

Grain wet.

May 24.—The plants are bleached and burned very severely. All injury of the "concentrated" type, and about two-thirds of the total foliage affected. The beards are all bleached close to the heads. No bleach apparent on the heads or the culms close up to the heads. An extremely severe burn.

June 2.—The plants appear about as on May 24. Heads appear, however, to be developing about as normal. No heads are killed. The plants in the plot showed the extensive injury up to the time the whole plant began to dry up.

PLAT 97.

Plat 97 was taken as a check for the above plats 98 and 100. This plat was under a hood for two hours on May 23. No injury of any kind appeared on the plants. The only markings present on the leaves were those caused by the rust or bacterial disease.

Results of experiments in series 1c, Vallejo.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	1.4	1,047	322	270	84	452
83	1.4	960	363	330	91	439
Check	1.4	880	295	231	78	413
98	2.8	1,756	596	558	94	824
100	1.4	766	303	283	93	358

Due to the large proportion of good heads to the total, in the case of the fumigated plats, the relative yield of the grain figured on the yield per unit total heads gives as follows:

Plat.	Yield per unit "total head," per cent.
Check	100
83	86
Check	100
98	99
100	85

EXPERIMENTS IN SERIES 2.

Series 2 comprises plats Nos. 14, 15, 16, 17, and 18, with check plat 19.

These plats were given 10-minute fumigations on 71 days between March 26 and June 13, as follows:

Date.	Number of fumigations.
Mar. 26	1
27	5
28	6
31	2
Apr. 1	4
2	3
3	3
5	3

Then one fumigation was given every day, except on April 9 and 26, May 23, 24, and 31, and June 7. Thus, the total number of fumigations (90) equaled a total of 900 minutes, or 15 hours per plat. Each plat received an average of 52 fumigations in the direct sunlight, 20 in shade—that is, under cloudy conditions—and 18 in partly cloudy weather.

During the first few days several of the plats were fumigated while there was some moisture present on the leaves. However, after the first few days no fumigations were made on these plats until the foliage was dry.

Plats 14, 15, 16, 17, and 18 were fumigated with mixtures of 1 2, 3, 4, and 5 parts SO_2 per million of air by volume, respectively. The average temperature of the air at the inlet was 24° C. At the end of the 10-minute periods the average maximum temperature at the far end of the cabinet was 31° C. The maximum temperature at the outlet end was 47° C; minimum 15° C. The average relative humidity of the air being blown into the cabinet was 55 per cent, which was 1 per cent greater than the average relative humidity at the outlet. The maximum relative humidity on March 28 was 95 per cent. At the time of the maximum temperatures the relative humidity was low, averaging about 30 per cent.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

The 10-minute fumigations with 2, 3, 4, and 5 parts sulphur dioxide per million served to keep the grain more or less badly bleached through the whole season. Repeated 10-minute fumigations throughout the growing season were very effective in reducing the yield of the crop on all plats except No. 14. This plat, which was fumigated with only 1 part SO_2 per million, showed only occasional and very slight signs of injury throughout the season, and in the end yielded practically the same as did the check plat. (See Pl. XIX, *A*.) This fact indicates that no "invisible" injury affected the yield of the grain. All other plats showed visible injury, increasing in extent from plat 15 to plat 18. These plats gave a decided decrease in yield, the yield from No. 18 which received concentrations of 5 parts SO_2 per million being less than 60 per cent of the check. This is a greater yield from No. 18 than was forecasted in May, when the foliage was so badly bleached and the culms so much shorter than the normal grain. Not only were the number of kernels of grains in the heads reduced, but also the weight of the individual kernels was reduced to a great extent. In this series it was noted that the fumigated plats had a fewer number of moldy heads than the check.

Summary of results of experiments in series 2, Vallejo.

[Fumigated 90 times between Mar. 28 and June 13, in 10-minute periods.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check			212	2.43	1.28	4.15	31	100	100
14	1	0.0026	251	2.42	1.24	3.94	31	100	97
15	2	.0052	195	2.17	1.05	3.88	27	89	82
16	3	.0078	174	1.84	.83	3.63	23	76	65
17	4	.0104	168	1.79	.86	3.42	25	74	67
18	5	.0130	167	1.45	.70	3.53	20	60	55

Detailed notes of plats.

March 28 (after sixth fumigation).—In the morning before fumigations of the day were started. No injury of any character on plats 14, 15, 16, and 17. Plat 18 is slightly faded and shows incipient "mottling" on some of the older leaves.

March 30 (after 12 fumigations).—Plat 14 shows no leaf markings.

Plat 15 shows no leaf markings.

Plat 16 shows fine "mottling" appearing on the oldest leaves.

Plat 17 shows considerable "mottling," general on the plat—the oldest leaves most affected.

Plat 18.—About 20 per cent of the leaves are "mottled." Some slight bleaching back from the tips.

April 2 (after 18 fumigations).—Plat 14 shows no leaf injury.

Plat 15 shows very incipient injury of the "mottled" type of bleach.

Plat 16 shows an increase of "mottled" area over that shown on March 30. Now about 40 per cent of the leaves affected and total area bleached about 15 per cent.

Plat 17 shows about twice as much injury as does No. 16. General injury, the fine white "mottling," but in some cases the "mottled" areas are merged into a general yellowish white bleach. About four-fifths of all leaves affected, and the bleached area equals about 25 per cent.

Plat 18 shows even more injury than does No. 17. The merging of the fine white "mottles" into a general yellowish white bleach has proceeded further than in No. 17. Greatest injury found in the oldest leaves and out near tip of all leaves. Practically all leaves affected. Area bleached is about 35 to 40 per cent of the total foliage.

April 7 (after 27th fumigation).—All plats show an increase in extent of injury. Even No. 14 is starting to show fine white "mottles" on some of the older leaves. On Nos. 17 and 18 the fine "mottling" has given place pretty generally to the white "concentrated" type of injury.

As it was decided that this treatment was too severe for getting the desired data, the fumigations were given only once each day after this date.

April 14 (36 fumigations).—Plat 14 shows a very small amount of the fine white "mottling." Also many yellowish-white leaves. The discoloration on these leaves, however, does not resemble sulphur-dioxide injury.

A. PLAT 17, APRIL 21, 1914, AFTER 42 FUMIGATIONS.

B. PLAT 15, APRIL 21, 1914, AFTER 42 FUMIGATIONS.

C. PLAT 14, APRIL 21, 1914, AFTER 42 FUMIGATIONS.

Plat 15.—The fine white or yellowish white "mottling" is more marked. Some of the leaves almost quite discolored to yellowish white, yet not like sulphur-dioxide injury.

Plat 16.—"Mottling" is slightly greater than in plat 15; also shows many yellowish-white areas on leaves.

Plat 17.—Undoubtedly severe sulphur-dioxide injury. Many leaves bleached back for considerable distance from the tips. Very little "mottling"—mostly all the "concentrated" type of injury. About 35 per cent of area bleached.

Plat 18.—About 40 per cent of foliage bleached killed back. "Concentrated" type of injury.

April 21 (42 fumigations).—Plat 14.—Believe that No. 14 is sustaining some injury, though the leaf markings are not the marks of characteristic sulphur-dioxide bleach, except for a few fine white "mottles." The front of the plat has thinner and lower stand than has the back. Undoubtedly due to natural causes.

Plat 15.—More characteristic sulphur-dioxide markings on this plat than on No. 14. (See Pl. XIX, *B*.)

Plat 16.—This plat very similar in appearance to plat 15. Both have undoubtedly sulphur-dioxide injury and at the same time an abnormal yellowish white bleach over many leaves which does not resemble sulphur-dioxide injury.

Plat 17.—This plat shows very severe bleaching that is unquestionably caused by sulphur dioxide. The tips of the leaves are bleached back for about one-fourth of the length. Practically all injury is the "concentrated" type. The oldest leaves, as usual, are the most affected. (See Pl. XIX, *C*, and Pl. XX, *B*.)

Plat 18.—Very severe bleaching all over the plat, especially in the front. About 50 per cent of foliage bleached, the "concentrated" type. None of the "mottled" type of injury apparent. (See Pl. XX, *A*.)

Comparison of unfumigated plants in check plat and fumigated plants in plat 16 is shown in Plate XVII, *B*, and Plate XXI, *A*.

April 21.—In all the plats the injury is greatest at the intake end. For example plat 17 at the rear end looks about the same as does No. 16 in front. Plat 18 at the rear end is slightly less injured than the front of plat 17. As explained in the general discussion of the work, the cause for the difference in the injury sustained in the front and back of the plats is due to the partial absorption of the sulphur dioxide from the mixture passing through the cabinets. In April, many analyses were made of the air in the cabinets during the fumigations. At the far end, the concentrations were generally only about 75 per cent of the concentration at the intake.

May 1 (51 fumigations).—All plats show about the same relative amount of damage, as has been evident for the last two weeks. Except for an abnormal number of yellowish white leaves around the base of plants, plat 14 seems to be normal and growing as plat 19, the check. The visible damage to the plats increases from plats 15 to 18, and in all plats is greatest at the front end. All plats have a shorter stand in the front than in the back. In no case are the plants killed, although in plats 17 and 18 some of the stalks are extremely small as compared with the normal plants.

May 11.—Plat 14.—About 20 to 25 per cent of foliage dried up and injured, due to all causes. Remaining green leaves high and fully developed.

Plat 15.—About 30 to 35 per cent of foliage dried up. Plants about as high as check except in front.

Plat. 16.—About 40 to 45 per cent of foliage dried up and part of injury undoubtedly due to sulphur dioxide.

Plat 17.—Ratio of dried up and injured foliage to total about the same as in No. 16.

Plat 18.—About 50 to 60 per cent of total vegetation injured.

Plats 16, 17, and 18 are undoubtedly behind the check plats in development. Plat 18 is at least two weeks behind.

Plat 19 (check plat).—Up to the present time this plat has shown practically no injury or yellowing of the leaves. At this time some yellowing appears, which is undoubtedly due to a bacterial disease. At this date the grain in plat 19 is heading out, as are the plants in plats 14 and 15.

May 18.—The plats have about the same relative growth as on May 11. Plats 14 and 15 are heading out very well. Plat 16 is slightly behind the check plat. Plats 17 and 18 are decidedly behind plat 19. The heads in the front of plat 17 and plat 18 are very small. The number of dead leaves around the base of the plants is increasing. The top two or three leaves are the greenest. In plats 17 and 18 these top leaves show some signs of damage. No bleach or drying up noted in the heads themselves.

May 29.—Plat 14.—The grain in this plat is normal in size and general appearance. The height of the plants throughout the length of the plat seems to be nearly equal.

Plat 15.—The first half of the plat is lower and thinner than the back. The upper leaves show some slight markings resembling sulphur dioxide injury. Last half of plat looks normal and as high as check.

Plat 16.—The leaves that are still green show some sulphur dioxide bleaching. The heads do not show any injury but are shorter and less developed than in the check plat.

Plat 17.—This plat is slightly worse than No. 16, especially in the front half. The leaves that are yet green show sulphur dioxide markings. Heads untouched but are shorter and not developed.

Plat 18.—In this plat some of the heads are still in the sheath. Plants are very short. All of the few green leaves in the plat show sulphur dioxide injury, principally the "mottled" type. The few heads developed, beyond the fact that they are very short, show no signs of injury.

June 13.—At this time nearly all the foliage on the plats, as over the whole field, was dried up. The heads were fully developed and the grain starting to harden. Plats 14, 15, and 16 were about as well developed as the check plat. Plats 17 and 18, however, were behind the others, the heads being still green, as were many of the stems. As all the grain was beginning to harden, it was decided to stop fumigation and allow the grain to ripen.

June 26.—At this time plats 14, 15, 16, and 19, the check, were ready to cut.

Plat 14.—Grain appears perfectly normal. Straw is taller than the neighboring untreated grain.

Plat 15.—Grain appears almost normal, especially at the rear end. Heads not so well filled out.

Plat 16.—Decided difference in appearance of heads between plat 16 and check. Smaller heads and lighter grain.

Plat 17.—Not quite ready to cut, although most of the heads are ripe.

Plat 18.—This grain is the worst looking in the whole field. The stalks are short and the heads small. Grain not ripe.

It was decided to leave the plats uncut until plat 18 was ripe. These plats were cut on July 2, at which time plats 17 and 18 were ripe. During the time June 13 to July 2, when the grain was allowed to grow without undergoing fumigation, the plants in plats 17 and 18 showed signs of recuperation. It is believed that had the fumigations continued until late in June the yield for these plats would have been even less than was obtained.

Area sampled from each plat was 2.8 square meters.

A. PLAT 18, APRIL 21, 1914, AFTER 42 FUMIGATIONS.

B. TYPICAL PLANTS IN PLAT 17, APRIL 21, 1914, AFTER FORTY-TWO 10-MINUTE FUMIGATIONS.

A. UNFUMIGATED PLANTS, APRIL 27, 1914, FROM CHECK FOR PLATS 14 TO 18.

B. SPECIAL FUMIGATION CABINET.

Results of experiments in series 2, Vallejo.

[Ninety 10-minute fumigations between Mar. 28 and June 13.]

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	2.8	1,446	594	492	83	630
14	2.8	1,701	702	637	91	794
15	2.8	1,187	547	495	91	523
16	2.8	894	496	455	94	377
17	2.8	849	472	442	94	378
18	2.8	681	468	432	92	301

The relative yield of grain based on weight of gra n per unit total heads is as fol ows:

Plat.	Per cent.
Check	100
14	107
15	100
16	78
17	79
18	66

EXPERIMENTS IN SERIES 3.

This series consisted of plats 31 to 35, inclus ve, with their checks. These plats were given 186 fum gations of five m nutes' duration each on 61 of the 73 days between April 1 and June 12, inclusive. The average number of fumigations per "fumigation day" was three, the maximum our. The average temperature of the inlet was 24° C. and of the outlet 29° C. The average relative humidity recorded at the far end of the cabinet was about 64 per cent, as against 58 per cent at the inlet. The total time under the cabinet for each plat was 930 minutes, or 15 hours and 30 minutes.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

Repeated 5-minute fumigat ons with concentrations of 3, 4, and 5 parts SO_2 per million parts of air, by volume, were very effective in reducing the yield of the gra n in the plats receiving the treatment. One hundred and eighty-six fumigations of five minutes' duration, w th 4 and 5 parts SO_2 per million reduced the yield to a lower point than did 90 10-minute fumigations. Plat 31 fumigated with only 1 part SO_2 per million, yielded more than he chec . This plat showed only the slightest traces of injury on several occasions dur ng the season. Plat 32, which was fumigated with 2 parts SO_2 per million, showed decided injury to the foliage throughout the whole season. The yield, however, was the same as that of its check. Plat 35,

which received concentration of 5 parts SO_2 per million, gave a yield of only 50 per cent of its check. No evidence to support the theory of "invisible damage" was obtained from this series. In fact, the evidence is all against the probability of "invisible damage." The percentage of moldy heads in the check and fumigated plats was about the same in both.

Plate XXII shows the appearance of the barley after 25 5-minute fumigations.

Summary of results of experiments in Series 3, Vallejo.

[186 fumigations—April 1 to June 12—each of 5-minutes duration.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check	0	.....	213	2.56	1.30	4.38	30	100	100
31	1	0.0026	186	3.00	1.51	4.31	35	117	115
32	2	.0052	219	2.68	1.28	3.51	36	105	98
33	3	.0078	154	2.04	1.01	3.32	30	86	84
Check	0	.....	198	2.18	1.10	4.29	26	100	100
34	4	.0104	203	1.29	.62	3.22	19	59	56
35	5	.0130	219	1.34	.54	3.21	17	61	49

Notes on plats 31 to 35, inclusive.[a]

April 2.—7 fumigations.

Plats 31 and 32.—No injury.

Plat 33.—Slight sulphur dioxide injury at the front end. Large blotches bleached white where there was moisture on the leaves at the time of fumigation.

Plat 34.—Injury of same character as in plat 33, but over larger proportion of area.

Plat 35.—Shows same bleached areas as plats 33 and 34 and also same mottled areas.

April 8.—22 fumigations.

Plat 31.—Shows no injury whatever.

Plat 32.—Shows very faint traces of the "mottled" type of injury.

Plat 33.—Blotches noted on April 2 still apparent; "mottling" also noted.

Plat 34.—A considerable portion, about 15 per cent, of foliage area affected. Some bleached blotches as noted April 2, but mostly the "mottled" type of injury.

Plat 35.—A considerable increase in the "mottled" area. Some of the "concentrated" type appearing in the solid bleach back from the tips of the leaves.

April 17.—49 fumigations.

Plat 31.—Except for slight yellowing of some of the leaves in the front of the plat, no injury is visible.

Plat 32.—More yellowing of leaves in the front of plat than in 31 and "mottling" also apparent. Plants smaller in back than in front.

Plat 33.—The marking about the same as in 32, only more general. Plants in center of the plat are lower than the average.

Plat 34.—In the front of the plat there is considerable injury of the "concentrated" type. In the last half the injury is practically all the "mottled" type.

[a] See Plates XXIII, *A*, *B*, and *C*, and XXIV, *A*.

BLEACHING OF GRAIN LEAVES BY 25 5-MINUTE FUMIGATIONS WITH DIFFERENT PROPORTIONS OF SULPHUR DIOXIDE.
Sample 1, 2 Parts per Million; Sample 2, 4 Parts per Million; Sample 3, 5 Parts per Million.

Plat 35.—The injury in this plat is greater than in 34. A larger area injured; bleach the "concentrated" type. Only the last few feet of the plat contains the "mottle" type of injury.

April 24.—71 fumigations.

Plat 31.—An increase in the number of yellowish leaves over those existing on April 17.

Plats 32, 33, and 34.—Show about the same amount of sulphur dioxide injury as on the 17th.

Plat 35.—Decidedly worse than on the 17th, more than half the foliage being badly bleached and injured.

May 1.—86 fumigations.

All plats are looking somewhat worse than on previous days. The yellowish leaves in 31 are more than normal, and in this plat there are signs of incipient "mottling." On all plats there are a large number of dried basal leaves.

May 11.—110 fumigations.

Plat 31.—Believe that the abnormal number of yellowish leaves in this plat is due to a great extent to fungi. Yellowing about 10 per cent more than normal. Some tips are "mottled." Very little, if any, characteristic sulphur dioxide injury.

Plat 32.—About one-third of the foliage more or less injured by sulphur dioxide or fungi. A part of this undoubtedly direct sulphur dioxide "mottling." Injury greatest at the inlet end.

Plat 33.—About half of the leaves affected. A great proportion of the injury is due to sulphur dioxide. Smallest plants are near the center of the plat.

Plat 34.—About two-thirds of the leaves affected. Plants are smaller than 33. Some "mottled" areas, but general bleach except on young leaves is the "concentrated" type.

Plat 35.—No green leaves except at the tops of the culms. About three-quarters of all foliage dried up or discolored. Plants are smaller and heads are not so well developed as in the check.

May 29.—152 fumigations.

Plat 31.—The plants in this plat are as high and well developed as any in the surrounding untreated plats. Has about the same number of fungi discolored leaves as the check plats and other portions of the field. No traces of characteristic sulphur dioxide injury showing.

Plat 32.—The plants in this plat seem about normal. Some signs of sulphur dioxide bleach evident, but the general drying up of the whole plant obscures the sulphur dioxide injury to a great extent.

Plat 33.—Nearly all the leaves are bleached more or less. The plants are shorter than in 31 or 32, but longer than in 34.

Plat 34.—The culms here are quite short. Some of the heads still "in the boot." All foliage is drying up. Old sulphur dioxide injury very evident.

Plat 35.—The culms are shorter even than in 34. Many heads "in the boot." No heads are bleached or injured directly.

June 13.—All foliage is dried up. The heads are practically filled out, except in 34 and 35. These heads are probably as well developed as they will be, and the grain in these heads is doughy. Fumigation stopped and the grain allowed to harden without any further fumigation.

June 26.—The plats were all ripe and ready to cut at this date, so that they were not set back materially. Plat 31*a*, a plat that had never been under a cabinet, was cut as a check for plats 31 and 32. Plat 36, which had been fumigated with air containing no sulphur dioxide, was taken as a check for plats 34 and 35, for the soil condition of plats 34, 35, and 36 was very similar. As a check for plat 33, which had a rather poor stand in the middle of the plat, the average of plats 31*a* and 36 was taken.

For all plats, except 36, a strip (61 by 459 cm.=2.8 square meters) through the center was taken as a sample. Samples from 36 were 62 by 305 cm.=1.9 square meters in area.

Results of experiments in series 3, Vallejo.

[186 fumigations—Apr. 1 to June 12—each of 5-minute duration.]

Plat No.[a]	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check *a*	2.8	1,529	598	531	89	695
31	2.8	1,560	520	455	88	689
32	2.8	1,646	613	569	93	726
33	2.8	880	432	369	86	372
Check *b*	1.9	821	376	328	87	360
34	2.8	735	568	500	88	312
35	2.8	821	613	544	89	296

[a] To obtain the figures on the relative yield from plat 33, the average of the two check plats *a* and *b* was taken as standard.

EXPERIMENTS IN SERIES 4.

The plats included in this series are 37, 38, 39, 40, 41, and 42.

On nine days, between April 6 and 16, these plats were fumigated for a total of 33 times, between two and four times each day. Plat 39 was used as a check plat. Plats 37, 38, 40, 41, and 42 were fumigated with 1, 2, 3, 4, and 5 parts SO_2 per million, respectively.

The length of each fumigation was five minutes. The plats averaged 28 fumigations in the sun, 3 under cloudy conditions, and 2 under partly cloudy conditions. The average temperature of the air at the inlet was 21° C. and at the outlet 26° C., a rise of 5° C. in the travel through the cabinet. The average relative humidity of the air at the inlet was 63 per cent. No regular records were made of the humidity at the outlet end of the cabinet. At the start, April 6, the average height was about 25 cm. The plats were 121 by 610 cm., or 7.4 square meters, in area.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

Comparing the results of series 1 and series 4, it is evident that injuries resulting after twelve 5-minute fumigations were only slightly less than would have been produced by an hour's continuous fumigation of the same concentration. Plat 37, receiving 1 part sulphur dioxide throughout the period, was only slightly affected. Plat 38 was noticeably bleached, the "mottled" type prevailing. Plats 41 and 42 were severely affected. It was noted in all these short-time fumigations that the "mottled" type bleach was the general injury that first appeared. With the stronger doses this was replaced by the "concentrated" or "kill-back" type. The yield of plat 40 was approximately 5 per cent; plat 41, 10 per cent, and plat 42, 15 per

A. GRAIN IN PLAT 33, MAY 4, 1914, AFTER ONE HUNDRED 5-MINUTE FUMIGATIONS WITH 3 PARTS OF SO_2 PER MILLION PARTS OF AIR.

B. GRAIN IN PLAT 32, MAY 14, 1914, AFTER ONE HUNDRED AND FOURTEEN 5-MINUTE FUMIGATIONS. LEFT, UNFUMIGATED CHECK PLANTS; RIGHT, PLANTS IN PLAT 32.

C. GRAIN IN PLAT 34, MAY 14, 1914, AFTER ONE HUNDRED AND FOURTEEN 5-MINUTE FUMIGATIONS. LEFT, UNFUMIGATED CHECK PLANTS; RIGHT, PLANTS IN PLAT 34.

A. GRAIN IN PLAT 35, MAY 14, 1914, AFTER 114 FUMIGATIONS.

B. SPECIAL CABINET FOR FUMIGATION EXPERIMENTS.

C. NEAR VIEW OF FUMIGATION CABINET SHOWN IN PLATE XXI, *B.*

cent less than the yield of the check plat. Plats 37 and 38 gave approximately normal yields as compared with the check. Here again we have evidence that considerable bleaching during the early stages of the growth does not necessarily mean a decreased yield. A slight bleach may mean only a very slight loss, if any at all. No evidence of "invisible" injury affecting the yield was found.

Summary of results of experiments in series 4, Vallejo.

[33 fumigations—Apr. 6 to 16—each of 5-minute duration.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
								Per cent.	*Per cent.*
39 (check)	0	.....	238	3.07	1.68	4.27	39	100	100
37	1	0.0026	300	2.91	1.64	4.31	38	95	98
38	2	.0052	254	3.19	1.63	4.60	35	104	97
40	3	.0078	213	3.00	1.58	4.06	39	98	94
41	4	.0104	209	2.77	1.54	4.01	38	90	92
42	5	.0130	250	2.59	1.39	3.98	35	85	83

Notes.

April 8.—After sixth fumigation.

Plat 42.—Receiving 5 parts SO_2 per million parts of air is showing considerable signs of damage, the "mottled" type of bleach being evident.

Plat 41.—Also showing slight traces of the "mottling," especially on the older leaves.

Plats 37, 38, 39, and 40.—Show no signs of any injury whatever.

No fumigations on April 8 and 9.

April 12.—After 14 fumigations.

Plats 41 and 42.—Both plats are looking much worse than on April 8. In plat 42 much of the "mottled" bleach is turning into the "concentrated" type, bleaching solidly back from the tips of the leaves.

Plat 40.—Starting to show "mottling."

Plats 37, 38, and 39.—These plats are still uninjured and look quite normal.

April 17.—After 33 fumigations.

Plat 37.—No characteristic sulphur dioxide injury apparent. A few scattered yellowish leaves throughout the plat. No "mottling."

Plat 38.—About 15 per cent of the leaves are affected, either yellowish or "mottled." Some few leaves affected at tips.

Plat 39.—A few scattered yellowish leaves. Plants look the same as in the outside field. Perfectly normal, yellowish leaves not caused by fumigations.

Plat 40.—About 30 per cent of leaves affected. All injury the "mottled" type, except for a few isolated leaves "killed back" from the tips. Shows some yellow leaves also.

Plat 41.—Injury greater than in plat 40. About 40 per cent of foliage affected—"mottled" type bleach with a few scattered tips "killed back."

Plat 42.—Injury greater than in plat 41. About 50 per cent of foliage affected. Mostly "mottled" type of injury, some of the white "concentrated" type showing up near the front end of the plat.

Fumigation of these plats now ceased.

May 1.—

Plats 37, 38, and 40.—Show no signs of injury whatever. The plants appear normal and of about the same height as the check plat 39.

Plat 41.—Shows indication of previous injury by slightly abnormal number of dried basal leaves. No injury present in green foliage.

Plat 42.—Shows indication, as does plat 41, of previous injury by abnormal number of dried leaves. No injury whatever in green foliage.

May 18.—No signs of injury in any plats. The growth and development in all plats seem normal.

May 29.—The growth on plat 37 seems especially dense compared with the check and the other plats of this series.

Plats 40 and 41.—Somewhat thinner and smaller than the check.

On no plat is there any sign of previous injury, and the growth is apparently normal.

June 26.—All plats ripe and are cut for quantative results.

Area sampled for each plat 61 by 459 cm., or 2.8 square meters, through the center of the plat.

Results of experiments in series 4, Vallejo.

[33 fumigations—Apr. 6 to 16, 1914—each of 5-minute duration.]

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
39 (check)	2.8	2,041	665	575	86	968
37	2.8	2,436	838	733	87	1,204
38	2.8	2,268	710	618	87	1,005
40	2.8	1,702	568	495	87	782
41	2.8	1,615	583	480	82	741
42	2.8	1,814	700	584	83	814

These experiments were planned and carried out expressly for the purpose of fumigating under natural conditions, while the grain was "in the milk."

EXPERIMENTS IN SERIES 5.

Series 5 consists of plats 69 to 79, inclusive.

Data showing character of experiments in series 5, Vallejo.

Plat.	Parts of SO_2 per million parts of air.	SO_2 per cubic meter.	Number of fumigations.
		Grams.	
69a	Not under cabinet.	.....	.....
69	1.0	0.0026	35
70	2.0	.0052	35
71	0	.....	35
72	3.0	.0078	35
73	4.0	.0104	35
74	5.0	.0132	35
75	0	.....	10
76	2.0	.0052	10
77	4.0	.0104	10
78	6.0	.0156	10
79	8.0	.0208	10

Plats 69 to 74 each received 35 fumigations of two minutes' duration. They were made at 10 or 15 minute intervals for seven times in succession daily for five days—May 6, 7, 8, 10, and 11.

Plats 75 to 79 received only 10 fumigations of two minutes' duration. These were made at 15-minute intervals four times on May 10 and 11, and two times on May 12.

The plats were 61 by 305 cm. in area and thus could be covered by a short cabinet. The plats were shaded during fumigation. The cabinets were placed over the plats only during the 2-minute fumigations. The air and sulphur dioxide mixture was blown in by a fan placed at each end of the cabinet and allowed to escape through the center.

The object in blowing in this larger volume of air was to prevent any rise in temperature or change in humidity of the air around the plants in the cabinet during the fumigation. This object was accomplished. During the 2-minute period that the cabinet was placed over the plats, the rise in temperature was less than 1° C. and the humidity difference could not be determined. Thus it was assumed that the plants were being fumigated under natural conditions. All plants in the cabinet were kept in motion by the air currents. No motionless plants were noted. The total volume of air blown into the cabinet was 8 cubic meters per minute. During the fumigations the average temperature was 21° C. and the humidity 40 per cent.

No appreciable difference in the susceptibility of the plants to sulphur dioxide was noted. In seven 2-minute fumigations, or a total of 14 minutes, a slight mottling was noted on the plants that had been subjected to a concentration of 5 parts SO_2 per million parts of air. In fourteen 2-minute periods the bleach produced by this concentration was about the same as that produced by six 5-minute fumigations on plat 42 on April 7. Twenty-eight 2-minute fumigations produced about the same bleached area as an hour's continuous fumigation on plat 2 on March 20, or plat 46 on April 18, or plat 59 on April 28. The only difference was that by the 2-minute period fumigations the bleach produced was more the "mottled" type and in the hour's continuous fumigation it was more the "concentrated" "kill-back" type. As the "mottled" type developed it became more like the "concentrated" type.

The average yield of 69 and 70, which showed no injury even after the thirty-fifth fumigation, was within 3 per cent of the check. Plat 72, which showed slight injury, gave a yield 8 per cent less than the check. Plats 73 and 74 were quite severely injured at the end of the 35 fumigations, and their yields were 20 per cent less than the check. Plat 79, which received ten 2-minute fumigations with 8 parts SO_2 per million, was injured about as badly as plat 73 and gave a yield 11 per cent less than the check.

In these plats (73, 74, 78, and 79) the yield in the grain was surprisingly large. This was the period of the development of the

grain when it was supposed to be most susceptible to the sulphur dioxide gas. The visible bleach produced by the fumigations was very severe on 74 and 79, and a greater effect in decreasing the yield of the grain was anticipated.

Summary of results of experiments in series 5, Vallejo.

THIRTY-FIVE 2-MINUTE FUMIGATIONS, MAY 6, 7, 8, 10, 11.

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check	0	.....	261	3.57	1.59	4.28	37	100	100
69	1	0.0026	264	3.29	1.52	4.12	36	92	94
70	2	.0052	268	3.57	1.59	3.86	41	100	100
72	3	.0078	275	3.27	1.48	4.21	35	91	93
73	4	.0104	246	2.86	1.28	4.23	30	80	86
74	5	.0130	223	2.65	1.23	3.90	32	74	78

TEN 2-MINUTE FUMIGATIONS, MAY 10, 11, AND 12.

Check	0	.....	261	3.57	1.59	4.28	37	100	100
76	2	0.0052	275	3.40	1.53	4.45	34	95	96
77	4	.0104	263	3.31	1.52	4.40	34	93	96
78	6	.0156	230	3.00	1.48	4.44	33	84	93
79	8	.0208	202	2.93	1.41	4.30	33	82	89

Notes on plats 69 to 74, inclusive.

May 7.—Morning. Grain headed out "in the milk." After first seven fumigations given on May 6, plats 69, 70, 71, 72, and 73 showed no signs of injury whatever. Plat 74, which had received 5 parts SO_2 per million was slightly affected, the fine "mottling" being apparent.

May 8.—After 14 fumigations.

Plats 69, 70, 71, and 72.—Showed no signs of injury.

Plat 73.—Began to show faint signs of "mottling."

Plat 74.—Was decidedly "mottled."

May 9.—After 21 fumigations.

Plats 69, 70, 71, and 72.—Showed no injury.

Plat 73.—Slight "mottling."

Plat 74.—General "mottling" on the whole plat.

May 11.—After 28 fumigations.

Plats 69, 70, and 71.—No injury.

Plat 72.—Faint signs of "mottling."

Plats 73 and 74.—Show an increase of "mottled" areas.

May 12.—After 35 fumigations.

Plats 69, 70, and 71.—Show no injury.

Plat 72.—Slight sulphur dioxide injury visible. Fine "mottling" and yellowing of the tips of the oldest leaves.

Plat 73.—About 30 per cent of the foliage "mottled" or yellow.

Plat 74.—About half the leaves show yellow and white "mottling." "Concentrated" type bleach on the leaf tips.

May 29.—16 days after last fumigation.

Plats 69, 70, 71, and 72.—Show no signs of injury.

Plat 73.—Shows signs of previous injury by abnormal number of dried basal leaves.

Plat 74.—Previous sulphur dioxide injury still apparent. White "mottled" type of injury.

June 12.—All leaves dried up. Heads only still green. All heads look normal.

June 26.—Cut on this date. Areas cut for samples were each 2.3 square meters.

Notes on plats 75 to 79, inclusive.

All this grain "in the milk."

May 12.—After 10 fumigations.

Plat 75 (the check).—Showed no injury.

Plat 76 (2 parts).—Showed no injury.

Plat 77 (4 parts).—Showed very slight injury of the "mottled" type; noticed only on close examination.

Plat 78 (6 parts).—Showed decided injury of the "mottled" type.

Plat 79 (8 parts).—Very severe injury mostly of the "mottled" type, although some "concentrated" bleaching back from tips also noted. No heads injured.

May 28.—Plats 75, 76, and 77.—Show no injury.

Plats 78 and 79.—Show signs of the previous injury. Plat 79 quite severely injured No heads injured.

June 26.—Cut on this date. Area samples 2.3 square meters.

In the preceding table giving the yield, the yield of the three check plats has been calculated as one and used as an average check for the nine fumigated plats.

Results of experiments in Series 5, Vallejo.

[Two-minute fumigations.]

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
(a)	7.4	6,890	1,930	1,724	89	2,738
69	2.3	1,927	585	518	89	773
70	2.3	2,126	595	517	87	823
72	2.3	2,068	632	574	91	848
73	2.3	1,615	565	519	92	664
74	2.3	1,361	513	418	82	514
76	2.3	2,154	634	543	86	832
77	2.3	1,927	583	495	85	752
78	2.3	1,588	530	455	86	672
79	2.3	1,361	464	418	90	589

[a] Three check plats considered as one.

EXPERIMENTS IN SERIES 6.

This series comprises those plats which received light fumigations for comparatively long periods during the whole growing season. The series comprises plat 7 and its check, and plats 12 and 21 and their check.

It was the idea at the start of the tests to use the data from these plats to determine the extent of "invisible damage." However, as visible injury became apparent early and continued throughout the season, the "invisible" injury data could not be obtained. These plats were finally used to determine the effect on the yield of very dilute fumigations continued for relatively long periods daily, thereby keeping the plants slightly bleached throughout the whole season.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

Plat 7, which received 198 fumigations of 15 minutes' duration with 2 parts SO_2 per million parts of air by volume, showed considerable bleaching throughout the season, especially during the time when the grain was heading out. The final yield, however, was about the same as the check plats, the total weight of "grain and straw" being somewhat less (11 per cent); the weight of the "grain" itself being somewhat greater (10 per cent) than was obtained in the check plat.

Plat 12 received 181 30-minute fumigations with 1 part SO_2 per million parts of air—total, 90½ hours.

Plat 21 received 97 1-hour fumigations with 1 part SO_2 per million parts of air. Plat 21 was bleached to a far greater extent than was plat 12 throughout the season. The extent of the bleach was somewhat less in both these plats than in plat 7. It was noted that on April 17 the bleach on plat 21 after 47 hours' fumigation in 20 days was only slight as compared with the extensive bleach produced by 43 hours' fumigation on plat 9 in six days, March 20 to 25.

The total yield for plat 12 was practically the same as for the check plat. The yield of grain was 12 per cent less than that for the check. Plat 21 gave a considerably decreased total yield, being about 25 per cent less. The weight of the grain, however, was only 13 per cent less than the check.

The fact that while plats 12 and 21 gave a decreased grain yield and plat 7 gave an apparent increased yield compared with the check is to be explained by the difficulty of securing a suitable blank for plat 7. Undoubtedly the data for plat 12 and plat 21 are more nearly correct than for plat 7. Thus we must conclude that continued bleaching, even though extending not over 20 per cent of the foliage during the entire growing season, did affect the yield to the extent of 10 per cent.

These plats were situated where the soil cracked very badly during the dry season in late April and May.

Summary of investigations in series 6, Vallejo.

[Plats that received light fumigations for comparatively long periods during the whole growing season.]

Plat No.	Concentration of SO_2.		Length of time of fumigation.	Number of fumigations.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.				Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
			Minutes.			*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
Check	.....	.....	.....	.....	242	3.00	0.95	3.57	27	100	100
7	2.0	0.0052	15	198	216	2.68	1.04	3.64	29	89	110
Check	.0	.....	60	97	236	3.00	1.35	3.84	35	100	100
12	1.0	.0026	30	181	216	2.95	1.19	3.92	30	98	88
21	1.0	.0026	60	97	243	2.31	1.17	3.97	29	77	87

Relative yield based on grain per total head.

Plat No.	Per cent.
Check	100
7	111
Check	100
12	95
21	89

PLAT 7.

Fumigations were started on March 23, when the plants were from 8 to 10 cm. high. In the 82 days between March 23 and June 12 the plat was fumigated on 49. The maximum number of consecutive days of fumigation was 15. The maximum number of consecutive days when the plat was not fumigated was five. The plat was not fumigated on rainy days nor at times when the grain was wet with dew.

The total number of fumigations was 198, an average of four fumigations per day. The maximum number of fumigations on one day was seven. Each fumigation lasted 15 minutes and there was at least 30 minutes between fumigations. Of the 198 fumigations, 136 were made with the direct sunlight, 43 under clouds, and 19 with partly cloudy conditions. The average temperature of the air blown into the cabinet was 24° C.; the average at the outlet end of the cabinet was 34° C., or 10° C. higher than the inlet. The average relative humidity at the outlet was 54 per cent, or 6 per cent less than the average humidity of the outside air. The maximum temperature in the cabinet was 49° C. at the outlet end and was obtained under a very bright hot sun. At this time the difference between the inlet and outlet air of the cabinet was 18° C. The humidity recorded at this time was 28 per cent. The minimum temperature recorded of inlet air was 13° C. and of the outlet was 17° C. At the time of the maximum humidity (90 per cent) the temperature was 20° C. The total number of minutes that the plat was fumigated during the season was 2,970, or 49½ hours.

Notes.

March 25.—After 9 fumigations, no injury visible.

March 27.—After 18 fumigations, slight "mottling" of leaves noted, especially on the oldest leaves. Youngest leaves not affected. Occasional coalescing of "mottled" areas to form larger bleached areas.

March 31.—No fumigation March 29 or 30 during rains. The plants apparently recovered quite appreciably, due to rapid growth during the rains. Injury to foliage now less than 10 per cent.

April 3.—After 46 fumigations, the proportion of "mottled" or bleached areas about the same as noted on March 27. Except for the "mottling" the plants appear normal and healthy.

April 6.—No fumigations on April 4 and 5. Total to date, 51. The plants look about the same as on the 3d, perhaps a little better. Only a few scattered leaves are affected.

April 10.—No fumigations on the 8th and 9th. Total to date, 61. Few leaves scattered throughout the plat are bleached and tips of many others slightly affected. Not much change from the condition as noted on the 3d.

April 17.—One hundred and seven fumigations to date. The injury is increasing more rapidly than the growth, especially in the first half of the plat. In this part the injury is becoming the white "concentrated" type. The plants in this portion are smaller in size than in the back, but believe this partly due to natural causes as well as to fumigations. In the rear end of this plat the bleach is more of the "mottled" type, with slight yellowing of the foliage. No fumigations from the afternoon of April 18 to the morning of April 21.

April 21.—The plants have recovered somewhat during the four days of rest from fumigation. Are now about 30 cm. high. Many leaves are yellowish in color, which does not seem characteristic of sulphur dioxide bleach.

May 1.—One hundred and thirty-two fumigations. All the oldest leaves are badly bleached and dried up. The youngest leaves are not affected. Those leaves slightly older show the traces of "mottling." The leaves still older are generally "mottled," the "mottled" areas coalescing to form larger white bleached areas. The grain in No. 7 was not so well developed as in the check.

May 11.—One hundred and forty-five fumigations. About half of the foliage is bleached or yellowish. The yellowing (according to Dr. Blankenship) is due to fungi. The grain has been heading out for several days, but is later than the grain in the check. Appearance about the same as on May 1.

May 29.—One hundred and seventy-four fumigations. Bleaching general all over the plat. Worse at the inlet end than at the outlet. The development of the heads seems to be normal, though the heads are somewhat smaller than in the check plat.

June 12.—One hundred and ninety-five fumigations. All leaves are drying up as in all parts of the field. Heads still green and seem to be about the same size or even larger than in the check. Fumigations stopped and the grain allowed to dry and harden unfumigated.

June 26.—Heads still slightly green. Not ready to cut. The check plat for No. 7 was ripe and ready to cut.

July 2.—Plat 7 ripe and cut on this date.

Owing to the rather uneven growth of the grain in plat 7 it was difficult to select a check. Plat 20 was at first thought to be a suitable check, but in May another check was selected as being more like plat 7. The plants were about as thick on this check plat as on plat 7. A cabinet was never placed over this check. A second check plat was selected for No. 7, in which the grain was as short as in the front of No. 7. This check gave a very much smaller total yield per head, but the yield in grain was the same as the first check plat selected. The data obtained from the first plat was selected for comparison with No. 7.

PLAT 12 AND ITS CHECK, PLAT 20.

On 47 days, during the 79 days between March 25 and June 12, this plat received a total of 181 fumigations of 1 part SO_2 per million parts of air, or 0.0026 gram per cubic meter. These fumigations were 30 minutes in duration and were made from two to four times each "fumigation day."

The average temperature of the air at the inlet was about 22° C., and at the outlet was 37° C., a difference of 15° C. The average humidity at the outlet was 47 per cent or about 8 per cent less than at the inlet. The maximum temperature at the outlet was 49° C., and was recorded on a bright sunny day. At that time the average relative humidity at the outlet was 25 per cent.

One hundred and fifteen fumigations were made in the direct sunlight, 35 in cloudy weather, and 31 in partly cloudy weather. Total fumigation time was 5,430 minutes, or 90½ hours.

Notes.

March 28.—Seventeen fumigations. Only by very close observation could a slight "mottling" be detected. No other injury noted.

March 31.—Seventeen fumigations. None on March 28 or 29 during rains. Very slight "mottling" noted by careful observation.

April 3.—Thirty-two fumigations. On April 1, nine fumigations were given this plat. Slight injury to several leaf tips and some "mottling" evident.

April 10.—Fifty fumigations. "Mottling" on many leaves and some of the tips whitened. Injury less than 5 per cent at most.

April 17.—Eighty-six fumigations. Few leaves yellowish in color throughout the plat. Other leaves show fine white "mottling." No fumigations April 17 to 20.

May 1.—One hundred and thirty-four fumigations. Noticeable sulphur dioxide injury, all the "mottled" type. Many basal leaves dried up. Growth appears normal.

May 11.—One hundred and forty-eight fumigations. Plat shows noticeable sulphur dioxide markings, "mottled" type. Growth normal.

May 29.—One hundred and sixty-six fumigations. Very little injury that looked to be due to sulphur dioxide. Many yellow leaves and other dried-up leaves, but no more than in other parts of the field.

June 13.—One hundred and eighty-one fumigations. All foliage drying up. Heads still green, but look normal and full size. Plants shorter in front than in back. Fumigations ceased.

June 26.—Heads still slightly green and not ready to cut.

July 2.—Grain cut. Area sampled, 2.8 square meters through the center of the plat.

The check used for this plat was No. 20. This plat received the same treatment as No. 21, except that no SO_2 was added. Was under a cabinet for 1-hour periods. The plat selected originally as check for No. 12 was very thin and the grain was poor. Although the plat was cut on June 26, the yield of this check was not used in these calculations.

PLAT 21.

On 46 days, during the 67 days between March 26 and June 1, this plat received 97 fumigations of 1 part SO_2 per million parts of air, or 0.0026 gram per cubic meter. Each fumigation lasted for 1 hour, and they were given about two times a day. The average temperature of the air at the inlet was 24° C. The temperature at the outlet was not recorded regularly and an average figure can not

be given. There is no doubt that on hot, bright, sunny days the temperature at the outlet end of the hood got very high, probably about 49° C., especially near the end of the hour's fumigation. The highest recorded temperature was 47° C. The check plat No. 20 received the same treatment at the same time, except that no SO_2 was added. No marks of any injury appeared on No. 20, until late in the season, when some of the leaves turned yellow, due (according to Dr. Blankinship) to fungi. The same yellow leaves were common all over the field.

Notes.

March 28.—After two fumigations. No injury apparent.

March 31.—After six fumigations. Only slight traces of injury, if any at all.

April 3.—Sixteen fumigations. Many slightly "mottled" leaves evident. No "concentrated" type injury.

April 10.—Twenty-seven fumigations. Injury apparently no greater than on the 3d. Few leaf tops whitened, but general slight injury is the "mottled" type.

April 17.—Forty-seven fumigations. A few leaf tips bleached white, many leaves "mottled." Injury is very slight, however.

May 1.—Seventy-two fumigations. Injury is increasing over the plat. Most of the injury is the "mottling" and yellowing. Some of the bleach does not seem characteristic of sulphur dioxide injury. The plants are higher in front than at the rear. At this time it is apparent that the check plat is higher and has better stand than No. 21.

May 11.—Eighty-two fumigations. Dr. Blankinship identifies some of the yellowing and brownish "mottling" as due to fungi. However, some characteristic sulphur dioxide injury apparent, the "mottled" type being apparent on the whole plat.

May 29.—Ninety-five fumigations. Sulphur dioxide injury shows throughout the plat. Grain does not look so good as in the check plat.

June 5.—Fumigation stopped. All grain is practically dried up. Only head and culm still green.

June 26.—Grain in heads not hardened completely yet, but about as well ripened as the check, No. 20, so both left at this time.

July 2.—Both No. 20 and No. 21 were cut on this date.

Results of experiments in series 6, Vallejo.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	2.8	2,041	679	568	84	542
7	2.8	1,624	606	519	86	539
Check	2.8	1,982	661	553	84	745
12	2.8	1,787	605	541	89	646
21	2.8	1,588	681	589	86	691

EXPERIMENTS IN SERIES 7.

These plats were intended for the determination of "invisible" injury. One plat (No. 26) was fumigated to a very slight "mottled" bleach in 15 days by 29-hour fumigations of 0.5 part SO_2 per million

parts of air by volume. With the initial appearance of the bleach the fumigations were stopped, the idea being to allow the plant to recover before resuming them. However, the bleach apparently continued to develop, giving the characteristic "developed mottle." Dr. Blankinship identified some of this injury as being due to a fungus disease. The slight injury due to sulphur dioxide evidently made the plants more susceptible to fungus disease. Because of this doubt concerning the cause of the "mottled" areas and the slowness with which the plant recovered the fumigations were not resumed. Plat 44 was carried through the season from April 15 consistently as an invisible-damage experiment.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

The yield from plat 26 of total weight of "heads and straw" was 15 per cent less than the check, but the "grain" yield was 6 per cent greater. The yield from plat 44 of total weight of "heads and straw" was 10 per cent greater than the yield from the check plat, and the "grain" yield was the same as that of the check. Both of these plats gave evidence that there was no invisible injury affecting the yield.

Summary of results of experiments in series 7, Vallejo.

Plat No.	Concentration of SO_2.		Length of time of fumigation.	Number of fumigations.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.				Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
			Minutes.			*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
Check....	0	.....	60	62	311	3.11	1.55	4.54	34	100	100
44.....	0.5	0.0013	60	62	344	3.44	1.54	4.39	35	111	99
Check....	0	.....	60	28	295	2.95	1.22	3.86	31	100	100
26.....	0.5	.0013	60	29	252	2.52	1.30	4.12	31	85	106

PLAT 26 AND CHECK PLAT 27.

Fumigations started on March 31 and continued to April 15, during which time the plats received 29 fumigations each, plat 26 receiving 0.5 part sulphur dioxide per million parts of air by volume and plat 27 atmospheric air. The length of time of each fumigation was one hour.

Notes.

April 16.—Slight "mottling" appeared on No. 26. Fumigation ceased.

April 20.—Five days after the last fumigation the "mottled" areas had increased greatly in size. Injury was about 15 per cent of total area. Possibly some of this "mottling" due to fungi, according to Dr. Blankinship.

May 11.—No injury was evident. The plat was not fumigated again, but allowed to grow normally, to determine whether this slight injury affected the yield.

No injury of any kind had been found on No. 27 at any time.

May 29.—Grain in No. 26 looked better than in No. 27, the check.

June 26.—Both plats cut. Area sampled 2.8 square meters in center of plat.

PLAT 44 AND ITS CHECK NO. 43.

Between April 15 and May 1 these plats received 3-hour fumigations. At that time, May 1, a slight sulphur dioxide injury was visible on No. 44. Also there was present a few scattered yellowish leaves. Fumigations were stopped. Between May 12 and June 1, the plats were given 23 fumigations, and between June 1 and June 12 they were given 6. Thus the total number of fumigations was 62. At no time was there any characteristic sulphur dioxide injury present, although there were several times when the slightest injury was suspected. The yellowed fungi-colored leaves were present, perhaps more than in normal untreated grain.

Plat 43 showed no injury during the fumigations and was considered to be a very good check for No. 44.

Both plats were ripe and cut on June 26. Area cut, 2.8 square meters.

Results of experiments in series 7, Vallejo.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportions of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	2.8	1,674	538	473	88	733
44	2.8	1,560	548	457	83	706
Check	2.8	2,467	836	758	91	923
26	2.8	1,728	686	640	93	773

EXPERIMENTS IN SERIES 8.

Series 8 consists of those plats which were fumigated at different stages of the growth to determine the effect of sunlight and shade and temperature and humidity conditions on the susceptibility of the plants to sulphur dioxide. They were not carried through to quantitative results.

The experiments were subdivided as follows:

(*a*) Fumigations made under high humidity conditions.

(*b*) Hour-period fumigations to compare injury under sunlight and shade conditions.

(*c*) Five-minute fumigations in the shade.

(*d*) Comparison 2-minute fumigations in sunlight and shade.

(*e*) Comparison of injury resulting from hour, 5-minute, and 2-minute doses.

FUMIGATIONS MADE UNDER HIGH HUMIDITY CONDITIONS.

In this series are included plats 23, 24, and 25. These plats were fumigated when the barley leaves were wet and the humidity of the air inside and outside the cabinet was high.

PLAT 23.

Grain 10 to 13 cm. high.

Fumigated with 1 part SO_2 per million parts of air in 30-minute periods, as follows:

Results of fumigations with 1 part SO_2 per million parts of air in 30-minute periods, series 8, Vallejo.

Date.	Number of fumigations.	Average in cabinet.		Notes.[a]
		Temperature.	Humidity.	
		°C.	Per cent.	
Mar. 29	1	12	95	No injury.
Mar. 30	6	16	90	Produced noticeable bleaching, white blotches rather than "mottling."
Apr. 4	4	18	92	Added to injury, mostly blotches.
Apr. 8	4	18	96	Added considerable to injury.

[a] The bleaching took place generally in blotches where the drops of water had stood on the plants during the period of fumigation. A surprising amount of injury, about 20 per cent of foliage affected, was produced by 15 30-minute fumigations of 1 part SO_2 per million parts of air, as compared with the results obtained on No. 9, which received 1 part SO_2 per million parts of air for 43 hours.

PLAT 24.

Grain 12 to 15 cm. high.

Fumigated with 2 parts SO_2 per million parts of air in 15-minute periods, as follows:

Results of fumigations with 2 parts of SO_2 per million parts of air in 15-minute periods, series 8, Vallejo.

Date.	Number of fumigations.	Average in cabinet.		Notes.[a]
		Temperature.	Humidity.	
		°C.	Per cent.	
Apr. 4	4	21	97	Slight injury noted.
Apr. 8	4	18	96	Decided bleach.
Apr. 9	4	21	95	About 30 per cent of foliage bleached.

[a] Injury greatest in front portion of the plat. The bleach just appeared in spots where the water had stood on the plants. Some "mottling" appeared also on the 9th in the back part of the plat. A surprising amount of damage was done in 12 15-minute fumigations, as compared with the injury done on plat 8 under lower humidity conditions.

PLAT 25.

Grain 8 to 10 cm. high.

Fumigated with 2 parts SO_2 per million parts of air in 15-minute fumigations. Ten fumigations on March 30 and two fumigations on March 31.

Average temperature in cabinet, 20° C.

Average relative humidity in cabinet, 88 per cent.

Notes.

The first half of the plat was badly injured. The injury generally noted in blotches over irregular areas where the vegetation was wet at the time of fumigation. Many leaf tips bleached back. At the back end, where the concentration of SO_2 was found by analysis to be only about 1 part per million, the injury was of the "mottled" type.

General Notes on Plats 23, 24, and 25.

These fumigations have shown that the grain is especially susceptible to the sulphur dioxide under highly humid conditions. When water is present, it absorbs the SO_2 rapidly and passes it along into the plants, so that moist areas will be bleached when the adjacent dry areas are not. The plants recovered rapidly, as did all plants fumigated at this date. No especial notes were made of the rate of recovery.

HOUR-PERIOD FUMIGATIONS TO COMPARE INJURY UNDER SUNLIGHT AND SHADE CONDITIONS.

The following experimental plats were fumigated to determine whether the barley was more or less susceptible to SO_2 in the hot sunlight than in the shade.

PLATS 45 AND 46.

April 18.—These plats were fumigated at the same time with 5 parts SO_2 per million parts of air by volume for one hour. No. 45 was fumigated in the shade, caused by burlap placed over the cabinet. Temperature, 31° C.; humidity, 50 per cent.

Plat 46 was fumigated in the direct sunlight; average temperature of air, 46° C.; humidity, 40 per cent.

The same volume of air was blown into both and, except for sunshine and shade, the conditions on the two plats were about identical. The injury to plat 46 was decidedly greater than to plat 45, by about 15 to 20 per cent. Plat 46 had a greater proportion of leaves bleached, and the bleach was more largely the "concentrated" type than in plat 45. Plat 46 was fumigated again on the two following days and then allowed to grow to maturity for quantitative purposes. Plat 45 was well recovered and showed no signs of injury by May 17.

PLATS 47 AND 48.

April 18.—These plats were fumigated with 4 parts of SO_2 per million parts of air for one hour—plat 47 in the sun and plat 48 in the shade.

Average temperature in plat 47, 43° C.; humidity, 55 per cent.

Average temperature in plat 48, 29° C.; humidity, 46 per cent.

The injury to plat 47 was greater than the injury to plat 48. Both showed more of the "mottled" type of injury than of the "concentrated," and the bleaching did not develop fully for several days. The injury was about 15 per cent greater in plat 47 than in plat 48. By May 11 practically all signs of this injury had disappeared and the grain appeared normal.

From the preceding experiments, 45, 46, 47, and 48, it is evident that the action of the sulphur dioxide on the plants or the absorption of the gas by them takes place more rapidly in the hot sunlight than in the shade.

FIVE-MINUTE FUMIGATIONS IN THE SHADE.

Because the "shaded" plats 45 and 48 showed relatively less injury than the "sunny" plats 46 and 47, fumigated for one hour under the same conditions, it was decided to fumigate several plats in the shade for short periods.

The cabinet used was 3.05 meters long. The shade was furnished by a burlap screen. The plats so fumigated were 49, 50, and 51, these plats respectively receiving fumigations of 1, 2, and 3 parts of SO_2 per million parts of air by volume.

Six 5-minute fumigations were given to each on April 19, and three on April 20 and 21, or a total of 12.

April 20, morning.—Plat 51, which had received six fumigations of 3 parts of SO_2 per million, began to show fine white "mottling".

Plat 50 showed a slight "mottled" area, but much less than in plat 51.

April 21, afternoon.—The "mottled" areas had increased to a considerable extent on No. 50 and No. 51. No injury showed in No. 49.

The fumigations were stopped, as it was evident that with 5-minute fumigations there was no great difference in the injury produced under the shade than under sunlight, and to continue further would duplicate plats 31 to 35 or 37 to 42.

After the fumigation stopped the bleach continued to develop. The fine "mottling" gave place to the "developed-mottle" type of bleach in longitudinal striations. This must mean that at this stage of growth (plants just beginning to head out) the absorption of sulphur dioxide was very rapid, but the subsequent chemical change in the leaf went on rather slowly. The same phenomenon was noted on plat 26, and was discussed under series 7.

COMPARISON OF RESULTS OF 2-MINUTE FUMIGATIONS IN DIRECT SUNLIGHT AND IN SHADE.

PLATS 52, 53, 54, AND 55.

Between April 20 and April 25 these plats were all given 45 fumigations of two minutes each. These fumigations were made five at time, each alternating with two minutes of fumigation with the atmosphere of the field, containing no determinable amount of sulphur dioxide. Thus in the six days, April 20 to 25, the plats had nine applications of these alternating fumigations, or 90 minutes' total fumigation with sulphur dioxide.

Plats 52 and 54 received fumigations of 3 parts SO_2 per million, No. 52 in the shade, No. 54 in the direct sun. No. 53 and No. 55 received fumigations of 2 parts SO_2 per million, plat 53 being in the

shade and plat 55 in the sun. The plants were about 30 cm. high at this time, not yet headed out.

At the end of the 25th fumigation, or 50 minutes of total fumigation time, the plants in both plats 52 and 54 were "mottled" and there was apparently very little difference in the two plats.

At the end of the 45th fumigation plats 52 and 54 were much "mottled" and some "concentrated" type of injury was apparent. The difference in the extent of the injury between No. 52 and No. 54 was hardly determinable. At the end of the fumigations, plats 53 and 54 showed considerable areas that were "mottled." No "concentrated" type injury showed, however. Very little difference between the two plats 53 and 55 was noted.

In order to see whether fumigations under the same conditions at a later stage of growth would show any marked difference, the same type of fumigations were repeated on the same plats on May 12, 13, and 16. At this time all plats were looking normally healthy and free from injury of any sort, and were well headed out. Five doses—that is, a total of 25 2-minute fumigations—were given. At the end of these fumigations plats 52 and 54 showed considerable injury, the "mottled" type, and plat 53 and plat 55 slight injury. There seemed to be no marked difference in the extent of the injury in the shaded or sunny plats. By May 31 all signs of the injury had disappeared and the grain appeared normal in every way.

The temperature in the sunny plats was only 3° C. higher at the end of the 20-minute fumigation period than the temperature in the shaded plats. The relative humidity average was about the same in both sunny and shady plats. Thus it is evident that with temperature and humidity nearly the same, the susceptibility of the grain to sulphur dioxide gas is not greatly affected by sunlight or shade.

COMPARISON OF INJURY RESULTING FROM HOUR, 5-MINUTE, AND 2-MINUTE FUMIGATIONS.

PLATS 58, 59, 60, AND 61.

The notes on these plats are given in detail under the description of experiments in series 1*b*. From the data on these plats, it is evident that the humidity factor is of greater influence than the sunlight. Plat 58, fumigated in the sunlight with a humidity of 30 per cent, was less injured than plat 59, fumigated in the shade, with a humidity of 60 per cent. After the bleaching had fully developed, the extent of the injury to plat 60 (5-minute periods) and to plat 61 (2-minute periods) was about the same as plat 59, so that the factor of time length of any one fumigation did not seem to make any material difference.

PLATS 62, 63, 64, AND 65.

These plats were fumigated with 4 parts of SO_2 per million parts of air, as follows:

Plat 62 received two 1-hour fumigations on April 29 and May 1, in sunlight. Relative humidity 25 per cent.

Plat 63 received two 1-hour fumigations on April 29 and May 1, in shade. Relative humidity, 50 per cent.

Plat 64 received 24 5-minute fumigations on April 29 and 30 and May 1 and 2, in the shade. Relative humidity, 60 per cent average.

Plat 65 received 60 2-minute fumigations on April 29 and 30, and May 2 and 3. Relative humidity, 50 per cent average in the sun.

May 5.—After bleach fully developed, all plats more or less injured, mostly of the "mottled" type, but many leaves also contained the "concentrated" type. Plat 64 showed the greatest amount of injury. Plats 63 and 65 about the same and less than plat 64, while plat 62 showed the least amount of injury.

These tests confirmed the conclusions previously reached that the humidity conditions were important factors and were of greater influence than sunlight or shade. It was noted in all these plats that no damage had apparently been done to the heads themselves. Due to the irregularity of the plants in these plats, it was thought inadvisable to try to obtain any quantitative data on the yield, so that none of these plats was cut.

PLATS 67 AND 68.

These two plats were fumigated for one hour at the same time on May 4, with 3 parts of SO_2 per million parts of air by volume. Plat 67 was fumigated in the direct sunlight. Temperature 32° C., humidity 34 per cent. Plat 68 was fumigated in the shade. Temperature 21° C., humidity 65 per cent.

Both plats were injured, the "mottled" type of injury being predominant. Plat 68 was injured worse than plat 67, by about 15 to 20 per cent. The results on these plats bear out the conclusions that the humidity is more effective in influencing the injury sustained than sunlight or shade or even temperature.

EXPERIMENTS IN SERIES 9.

This series consists of those plats fumigated to determine the relative injurious effects of sulphur dioxide gas and sulphur trioxide vapor or fume.

It was suggested by some of our visitors, who were connected with the smelting industry, that some of the injury to the barley, which had been attributed to sulphur dioxide gas, was due to the presence

of sulphur trioxide vapor or fume in the cabinets, resulting from the oxidation of a slight amount of the dioxide. To investigate this possibility seemed very necessary, and a series of experiments for that purpose was started early in May when the grain was just beginning to head out.

For the purpose of producing a known quantity of sulphur trioxide, a contact conversion apparatus, as described below, was constructed in the Bureau of Mines laboratory and taken into the field at Vallejo.

DESCRIPTION OF APPARATUS FOR CONVERTING SULPHUR DIOXIDE TO SULPHUR TRIOXIDE.

The apparatus used in converting sulphur dioxide to sulphur trioxide is shown in figure 11.

A porcelain tube 2.5 cm. in diameter was placed in the center of two electrically heated furnaces *b* and *a*, *b* being the preheater, and *a* the conversion furnace. These furnaces were built with asbestos, and were wired with nichrome wire. They were heated from the 110-volt line, rheostats being placed in series to control temperatures. A thermocouple was inserted in *a* and connected with a galvanometer for measuring the temperature. The desired volume of air, measured through a capillary meter, was blown in at one end of the porcelain tube and passed through the preheater. The metered volume of sulphur dioxide was added at the other end of the preheater, the resultant mixture then being passed through the contact mass in the contact or conversion furnace *a* (fig. 11). This contact mass consisted of 10 grams of asbestos wool which contained 4 per cent platinum. The asbestos was platinized by soaking it in a solution of platinum chloride in alcohol and then burning off the alcohol. The air and gas mixture contained between 7 and 10 per cent sulphur dioxide. The temperature of the contact mass was kept between 430° and 450° C.

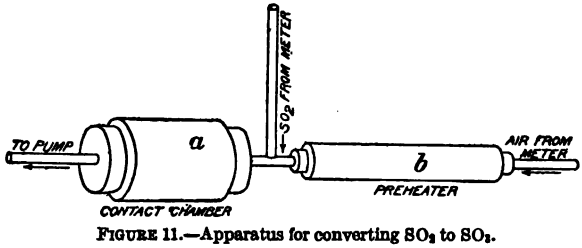


FIGURE 11.—Apparatus for converting SO_2 to SO_3.

A metered volume of sulphur dioxide gas was put through this apparatus and converted to sulphur trioxide. This was added to the intake of the blower and driven into the cabinet in the same manner as in the usual sulphur dioxide fumigations. No baffle box was used, as it was not needed and also because it would cause partial precipitation of the fume. The efficiency of the conversion in all tests was determined by the analysis of the sulphur dioxide in the volume discharged from the blower.

A small and indeterminable amount of the sulphur trioxide was precipitated in the fan and in the delivery pipe, so that the exact weight of the fume discharged into the cabinet per minute was not known. However, a fairly approximate value of the concentration was possible. A very small amount of trioxide in the air produced a visible fume. In cloudy weather the presence of 0.0032 gram per cubic meter (equivalent to the conversion of 1 part of SO_2 per million parts of air) was visible at some distance.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

The experiments in this series prove conclusively that sulphur trioxide fume or vapor was not responsible for any injury found in the plats fumigated with sulphur dioxide. Furthermore, these experiments prove that under dry atmospheric conditions, with the trioxide suspended as "dry fume," the injury that can be produced by a long fumigation with these fumes is slight. In fact, in three hours the fumigation of plants with a very dense fume, namely, 0.026 gram sulphur trioxide per cubic meter, produced no visible injury. That no material injury, visible or invisible, resulted from these long-time fumigations with sulphur trioxide fumes is shown in the yield of the plats 80, 82, and 89, compared with their checks, also plat 96 compared with its check. All of these plats gave yields that were practically the same as their checks. A comparison of the yields from the plats fumigated with sulphur trioxide and those fumigated with sulphur dioxide at the same time is very significant, showing a material decrease in yield from the plots fumigated with SO_2 and no decrease from the plats fumigated with SO_3. It is to be remembered that these fumigations took place during the time the grain was filling out in the head, and thus at the time when the deleterious influence of fumigation on the development of the grain would be a maximum.

Summary of results of experiments in series 9, Vallejo.

[Sulphur trioxide fumigations.]

Plat.	Concentration of SO_3 per cubic meter.	Length of time of fumigation.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
				Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
	Gram.	*Hours.*		*Grams.*	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check	0.000	.....	230	3.25	1.67	4.63	36	100	100
80	.015	2	268	2.97	1.63	4.68	35	91	98
82	.018	1	199	3.26	1.69	4.54	37	100	101
89	.021	2½	201	3.23	1.66	4.64	33	99	100
Check	.000	.....	211	2.96	1.79	4.88	37	100	100
96	.033	1½	218	2.87	1.72	4.22	41	97	96

Relative yield of grain based on total heads.

Plat.	Per cent.
Check	100
80	100
82	100
89	99
Check	100
96	112

Effect on yield of sulphur dioxide and sulphur trioxide fumigations during the period when the heads were filling out.

FUMIGATIONS WITH SULPHUR TRIOXIDE.

Plat.	Weight of SO_3 per cubic meter.	Length of time of fumigation.	Relative yield based on—	
			Straw and heads.	Grain.
	Gram.	*Hours.*	*Per cent.*	*Per cent.*
80	0.015	2	91	98
82	.018	1	100	101
89	.021	2½	99	100
96	.033	1½	97	96

FUMIGATIONS WITH SULPHUR DIOXIDE.

83	[a] 0.014	1	82	80
98	[a] .016	½	100	83
100	[a] .016	2½	85	70

[a] Weight of SO_2 per cubic meter.

PLAT 80.

Fumigated with sulphur trioxide fume.

Date, May 14, 1914.

Time, two hours.

Concentration of SO_3.—19 c. c. SO_2 converted per minute to 0.0616 gram SO_3, added to 4.2 cubic meters air per minute = 0.0147 gram SO_3 per cubic meter. This is equivalent to the conversion of 4.5 parts SO_2 per million parts of air by volume.

Results.—No injury resulted from this fumigation. No bleach appeared on the heads or on the leaves, either directly after the fumigation nor at any time later.

PLATS 82 AND 85.

Fumigated with sulphur trioxide fume.

Date, May 18, 1914.

Time, one hour for plat 82, one-half hour for plat 85.

Concentration of SO_3.—23 c. c. SO_2 converted per minute to 0.0747 gram SO_3, added to 4.2 cubic meters air per minute = 0.0178 gram SO_3 per cubic meter. This is equivalent to the conversion of 5.5 parts of SO_2 per million parts of air by volume.

Results.—No injury or bleach resulted from these fumigations. (Compare these results with those obtained on plat 83 following.)

PLAT 83.

Fumigated with sulphur dioxide gas.
Date, May 18, 1914.
Time, one hour.
Concentration of SO_2.—5.4 parts per million parts of air by volume.
Results.—Very severe injury resulted, about 50 per cent of the foliage being bleached with the "concentrated" type of injury. (Compare results with those obtained on plats 82 and 85 above.)

PLAT 86.

Fumigated with sulphur dioxide gas.
Date, May 19, 1914.
Time, one hour.
Concentration of SO_2.—3 parts per million parts of air by volume.
Results.—Slight injury resulted to the leaves and some of the beards. Mostly the "mottled" type. The results should be compared with those on plats 84, 87, and 88.

PLAT 84.

Fumigated with sulphur trioxide fume.
Date, May 19, 1914.
Time, one hour.
Concentration of SO_3.—11.3 c.c. SO_2 converted per minute to 0.0367 gram SO_3; added to 4.2 cubic meters air per minute = 0.0087 gram SO_3 per cubic meter. This is equivalent to the conversion of 2.7 parts of SO_2 per million parts of air by volume.
Results.—No injury or bleach resulted.

PLAT 87.

Fumigated with sulphur trioxide fume.
Date, May 19, 1914.
Time, one hour.
Concentration of SO_3.—12.6 c. c. SO_2 converted per minute to 0.0410 gram SO_3; added to 4.2 cubic meters of air per minute = 0.0098 gram SO_3 per cubic meter. This is equivalent to the conversion of 3 parts of SO_2 per million parts of air by volume.
Results.—No injury or bleach resulted.

PLAT 88.

Fumigated with sulphur trioxide fume and sulphur dioxide gas.
Date, May 19, 1914.
Time, one hour.
Concentration of SO_3.—12.6 c. c. SO_2 converted per minute to 0.0410 gram SO_3; added to 4.2 cubic meters of air per minute = 0.0098 gram SO_3 per cubic meter. This is equivalent to the conversion of 3 parts of SO_2 per million parts of air by volume.

Concentration of SO_2.—1 part of SO_2 per million parts of air by volume.

Results.—No injury or bleach resulted.

PLAT 89.

Fumigated with sulphur trioxide fume.

Date, May 19, 1914.

Time, two and one-half hours.

Concentration of SO_3.—27.3 c. c. SO_2 converted per minute to 0.0887 gram SO_3; added to 4.2 cubic meters of air per minute = 0.0211 gram SO_3 per cubic meter. This is equivalent to the conversion of 6.5 parts of SO_2 per million parts of air by volume.

Results.—No injury or bleach resulted. The results should be compared with those on plat 90.

PLAT 90.

Fumigated with sulphur dioxide gas.

Date, May 20, 1914.

Time, one-half hour.

Concentration of SO_2.—6.5 parts of SO_2 per million parts of air.

Results.—Injury and bleach produced on the foliage. Some "concentrated" but mostly the "mottled" type.

PLATS 91 AND 93.

Fumigated with sulphur trioxide fume.

Date, May 20, 1914.

Time, three hours for plat 91; one and one-half hours for plat 93.

Concentration of SO_3.—33.6 c. c. SO_2 converted per minute to 0.1100 gram SO_3; added to 4.2 cubic meters of air per minute = 0.026 gram SO_3 per cubic meter. This is equivalent to the conversion of 8 parts of SO_2 per million parts of air by voulme.

Results.—No injury or bleach resulted on either plat. The results on plat 94 should be noted.

PLAT 94.

Fumigated with sulphur dioxide gas.

Date, May 20, 1914.

Time, one-half hour.

Concentration of SO_2.—8 parts per million parts of air.

Results.—This half-hour fumigation with 8 parts of SO_2 per million parts of air produced very severe injury. Most of the foliage was bleached, as were also some of the beards on the heads. The injury was mostly the "concentrated" type. This severe injury is in marked contrast with the absence of injury produced by fumigations with the very dense fumes of SO_3 continued for long periods, as in fumigations on 91 and 93.

PLAT 95.

Fumigated with sulphur dioxide gas.

Date, May 21, 1914.

Time, one-half hour.

Concentration of SO_2.—Ten parts per million parts of air by volume.

Results.—Very severe injury resulted from this fumigation. Most of the injury the "concentrated" type, but some "mottled" type is also evident. Compare with the results obtained on plat 96 below.

PLAT 96.

Fumigated with sulphur trioxide fume.

Date, May 21, 1914.

Time, one and one-half hours.

Concentration of SO_3.—42 c. c. SO_2 converted per minute to 0.1368 gram SO_3; added to 4.2 cubic meters of air per minute = 0.0326 gram SO_3 per cubic meter. This is equivalent to the conversion of 10 parts SO_2 per million parts of air by volume.

Results.—No injury or bleach resulted whatever. Compare with the results obtained on plat 95 above.

PLAT 101.

Fumigated with sulphur dioxide and sulphur trioxide fume.

Date, May 25, 1914.

Time, two hours.

Concentration of SO_2.—0.0026 gram per cubic meter, or 1 part SO_2 per million parts of air.

Concentration of SO_3.—0.0065 gram per cubic meter. This is equivalent to the conversion of 2 parts SO_2 per million parts of air by volume.

Results.—In this plat there were many tall stalks which touched the top of the cabinet. These leaves and stalks and heads touching the cabinet sweated during the fumigations and were moist. After fumigations these moist leaves and heads were spotted and dried up. A characteristic sulphuric acid drying out and burn was noted, which to only a very slight degree resembled the sulphur dioxide bleach. No other leaves or heads affected in the slightest degree.

PLAT 102.

Fumigated with sulphur trioxide fume.

Date, May 25, 1914.

Time, two and one-half hours.

Concentration of SO_3.—0.010 gram SO_3 per cubic meter. This is equivalent to the conversion of 3 parts SO_2 per million parts of air by volume.

Results.—In this plat, as in No. 101, were many tall heads and some leaves which touched the under side of the cabinet top and sweated

in the direct rays of the sun. After the fumigation these contact leaves and heads were shriveled and dried up. No bleach resembling SO_2 injury was evident. Other shorter leaves and heads were not affected in the least. In this fumigation fine dust that had been taken from the Selby roaster bag house was added through the fan, so that it was suspended in the air of the cabinet for some little time. After the fumigation this fine dust was found on the leaves and heads and also on the ground and outside the cabinet where it had escaped. No characteristic spotting of flue dust was noticed after fumigation. This dust was allowed to remain on the plants and no injury or spotting developed between May 25 and June 13, at which time the foliage was quite well dried up, due to maturity.

PLAT 103.

Fumigated with sulphur trioxide fume.

Date, May 26, 1914.

Time, two hours.

Concentration of SO_3.—0.0065 gram SO_3 per cubic meter. Equivalent to the conversion of 2 parts SO_2 per million parts of air by volume. Flue dust also added to blower and blown into the cabinet.

Results.—No injury resulted except to several isolated tall heads that were against celluloid top of cabinet, as noted in Nos. 101 and 102.

PLAT 104.

Date, May 27, 1914.

Time of fumigation, 3 hours.

Concentration of SO_2.—0.0026 gram per cubic meter, 1 part per million parts of air by volume.

Concentration of SO_3.—0.010 gram per cubic meter. Equivalent to the conversion of 3 parts SO_2 per million parts of air by volume. Fume added through the fan. Water also sprayed in on the grain.

Results.—Very slight SO_2 injury resulted where water had stood on plants. No injury to dry leaves.

PLAT 106.

Date, June 3, 1914.

Time, one hour.

Concentration of SO_3.—Unknown, but comparatively very large. Produced by blowing air through fuming Nordhausen acid, the fume being discharged into the fan and blown into the cabinet. A very dense cloud of fume in the cabinet. Not possible to see across because of fume.

Results.—Absolutely no visible injury resulted.

Several experiments were made between May 24 and June 5, Nordhausen acid being used for producing fumes. No data of the concentration of SO_3 in any case were obtained, but in all cases the air over the experimental plats was filled with a dense fume during

periods of time varying between 20 minutes and 2 hours. No visible damage was produced in any case, except in cases where the grain, leaves, or heads were pressed against the celluloid surface of the cabinet top.

The experiments using SO_2 fume were continued later in the laboratory of the Bureau of Mines, and the conditions under which the characteristic SO_2 or H_2SO_4 spotting is produced were determined approximately. This later work will be discussed elsewhere in this report.

Results of experiments in series 9, Vallejo.

Plat No.	Area sampled.	Weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	1.4	1,047	322	270	84	452
80	1.4	1,074	362	310	86	506
82	1.4	906	278	230	83	389
89	1.4	908	281	232	83	386
Check	1.4	880	295	231	78	413
96	1.4	933	305	280	92	481

EXPERIMENTS IN SERIES 10.

FIRST GROUP OF SPECIAL EXPERIMENTS.

The following experiments were conducted to determine the cause for the discrepancy between the results obtained in these experiments by the method of fumigation adopted and the results recorded by the many previous investigators. The method most commonly used by other investigators was that of adding a measured volume of sulphur dioxide to a known volume of air, inside a glass case or house in which the plants under investigation are placed.

Without going into a long discussion of the results obtained by these earlier investigations it is only necessary to state that a concentration of about 10 parts SO_2 per million has been reported to be the limit of dilution that would produce injury. In order to carry out some experiments similar in detail to the "fumigations" of other investigators we obtained a fumigation cabinet that had been constructed by the Balaklala Consolidated Copper Co. for the use of Dr. J. W. Blankinship. As shown in Plate XXIV, *B*, this cabinet was built of wood with glass sides and front. The frame and back were made of oak. The front consisted of two glass doors, hinged at the sides. The capacity of the cabinet was 0.15 cubic meter. In the back was a hole 10 cm. square for the introduction of the dish containing the chemical agents to produce sulphur dioxide.

In the first experiments at Vallejo a mixture was prepared, as in the regular fumigations, by adding a metered volume of sulphur dioxide to the intake of the fan, the volume discharged by the fan

being measured. This mixture was blown into the cabinet, through the hole in the back as it stood on the plat of grain selected, at the rate of about 1.72 cubic meters per minute for two minutes. After two minutes the hole was closed by a slide, and the rate of disappearance of the sulphur dioxide determined by analyses of samples taken from the cabinet at definite intervals.

EXPERIMENT 1, APRIL 2, 1914.

Cabinet placed over two barley plants, each about 25 cm. high. Mixture blown in for two minutes.

Kind of sample.	Parts of SO_2 per million parts of air.
Mixture blown into cabinet	7.0
Air in cabinet 1 minute after the cabinet was closed	2.0
Air in the cabinet 5 minutes after the cabinet was closed	.5
Air in the cabinet 10 minutes after the cabinet was closed	<.2

Believing that there was a possibility of some of the sulphur dioxide being lost by dispersion or diffusion due to very small cracks in the cabinet joints, the joints and corners were well sealed with putty on the outside before starting experiment 2.

EXPERIMENT 2, APRIL 2, 1914.

Kind of sample.	Parts of SO_2 per million parts of air.
Air blown into cabinet	10.0
Air in cabinet after cabinet was closed 1 minute	3.0
Air in cabinet 5 minutes after the cabinet was closed	.4
Air in cabinet 10 minutes after the cabinet was closed	<.2

On April 3 experiments were conducted as follows: The cabinet was sealed with putty except for a small hole in the center of the back where a glass tube was inserted. Through this glass tube was added a definite volume of SO_2 contained in a burette over mercury. A small fan revolving in one corner of the cabinet served to mix the SO_2 with the air. Analyses were made as in experiments 1 and 2 to determine the rate of disappearance of SO_2.

EXPERIMENT 3, APRIL 3, 1914.

The cabinet was placed over a single large plant about 30 cm. high. Fan was revolved to circulate about 1 cubic meter a minute, keeping the foliage of the plant in motion.

SO_2 added 3 c. c., calculated to equal 20 parts SO_2 per million parts of air by volume in the cabinet.

Kind of sample.	Parts of SO_2 per million parts of air.
SO_2 in sample taken one-half minute after SO_2 added	7.0
SO_2 in sample taken 1 minute after SO_2 added	4.2
SO_2 in sample taken 5 minutes after SO_2 added	<.2

Experiments such as the above three were repeated several times with approximately the same results, showing a very rapid disap-

pearance of the SO_2 from the atmosphere in the cabinet. Thus it is evident that in that method of fumigation there is no way of determining the time during which the plant is receiving a fumigation. Momentarily the plant may be in contact with the calculated concentration but the disappearance of the SO_2 is so rapid that the length of time of any fumigation is very small. The disappearance of the SO_2 may be due to a number of causes, namely, absorption by the foilage, absorption by the wood or the soil, or oxidation to SO_3.

In order to eliminate all possibility of leakage through cracks and to cut down the contact of the gas with the wood to a minimum, a glass case was constructed as shown in Plates XXI, *B*, and XXIV, *C*.

The sulphur dioxide was measured over mercury in a burette and passed into the cabinet through one of the glass tubes shown. A fan in the case served to keep the air in circulation to aid the mixing of the gas. Samples of the air were drawn out through the second glass tube. The capacity of the glass case was one cubic meter.

EXPERIMENT 4, APRIL 15, 1914.

Case placed on plants 35 cm. high. Volume of SO_2 added to the case, 25 c. c. Therefore, SO_2 equaled 25 parts per million parts of air by volume.

Kind of sample.	Parts of SO_2 per million parts of air.
Taken 1 minute after adding SO_2	10.0
Taken 5 minutes after adding SO_2	1.2
Taken 10 minutes after adding SO_2	$<$ .2

EXPERIMENT 5, APRIL 17, 1914.

Case placed over plants 35 cm. high. SO_2 added, 200 c. c., 200 parts per million.

Kind of sample.	Parts of SO_2 per million parts of air.
Taken 1 minute after adding SO_2	50.0
Taken 5 minutes after adding SO_2	7.0
Taken 10 minutes after adding SO_2	.5

Experiments were made later to determine the absorption over bare ground with no vegetation present, and the disappearance was found to be rapid, although not so rapid as when vegetation was present. Further experiments made with the glass case placed on paper to prevent absorption by the soil still showed considerable disappearance.

In order to determine whether or not this disappearance was due partly to the oxidation of SO_2 to SO_3, more careful work was required than could be done in the field. The work along these lines was continued in the Bureau of Mines laboratory at San Francisco and will be discussed elsewhere in this report.

The conclusions drawn from these experiments in the field at Vallejo were as follows:

1. Due to the fact that in many of the early investigations no attempt had been made to maintain a definite concentration for any period of time, the number of fumigations was a very indefinite basis for stating results.

2. If a sufficient number of these "fumigations," as applied in the other methods of investigation, had been applied in rapid succession so that the total time that the concentrations were present in the fumigating atmosphere was the same as in the fumigations given in this work, the same results would have been obtained.

SECOND GROUP OF SPECIAL EXPERIMENTS.

The claim had been advanced by several investigators doing work along similar lines that some of the injury in the fumigated plats was not due to sulphur dioxide, but was due to abnormal conditions existing while the plants were under the cabinet. The possibility of this trouble had been anticipated at the first, and every effort had been made to determine how extensive this might prove. As stated above, at no time did the check plats, fumigated with the air containing no determinable amount of sulphur dioxide under the same conditions as the regular fumigated plats, show any signs of bleaching or injury. Even Vallejo plat 10, which received seven hours' fumigation with sulphur dioxide free air in the direct sunlight daily on six successive days, did not show the slightest sign of injury.

Vallejo plats 20, 43, and 27, which received fumigations of hourly duration daily, showed no signs of bleach or other injury. No leaf markings whatever were apparent until early in May when the yellow fungus diseased leaves were present in the check plat as in all parts of the field.

At Davis the same condition was true, that the check plats fumigated showed no signs of bleach or any injury that was not also present on the whole field.

With these facts in view, it was safe to conclude that none of the injury or bleach produced in the fumigated plats was caused by any abnormal condition due to the cabinet being placed above the plants.

However, in order to study the markings or injury that might be brought about by these abnormal conditions when carried to the extreme, the following tests were made:

The glass case described above was placed above plants for varying periods of time, varying from 1 hour to 10 days. As the glass case sat squarely on the ground in most cases there was almost no circulation of air, and the glass surfaces were generally covered with drops of water from the sweating of the plants. Under the direct rays of the sun the temperature in the case was found to be as high as 52° C. However, except in one instance, no bleach resulted. In

this particular instance the plants were exceptionally tall and some of the leaves laid up against the top of the case. Moisture collected there and under the direct rays of the sun, there was produced a white blotched bleaching that was dissimilar to that produced in any of the sulphur dioxide fumigations. The leaves immediately below the contact leaves were wholly unaffected after being in the glass case for 10 successive days. Thus as very extreme treatment under glass failed to produce leaf markings or bleaches similar to that produced in the plats fumigated with sulphur dioxide, we were doubly assured that the injury attributed to sulphur dioxide was not sun scald nor caused by any abnormal conditions existing in the cabinet.

FUMIGATION EXPERIMENTS AT THE UNIVERSITY OF CALIFORNIA FARM AT DAVIS, CAL.

The field of barley selected for the experimental work was plowed 8 inches deep December 1 to 9, 1913, was harrowed on the 9th and again on the 12th of December, and disked 3 inches deep between February 11 and 17, 1914. On February 27 and March 2 it was again harrowed. Between March 2 and 4 Beldi barley was sown by drill and the field was again harrowed on March 5 and 6.

Fumigation work was started on April 10, when the plants were about 25 cm. high and well stooled out. The stand was about twice as thick as at Vallejo, and generally more even. However, there were several spots in the field where water had stood early in April and where the grain was low and uneven. At the time the tests were started no fungi diseases were noted.

All the fumigation work at Davis was done with a single cabinet and meter set (Pl. XXV, *A*). Only a few long-time fumigation experiments were made at this field, and these were made to determine the effect of severe bleaching on the ultimate yield rather than to determine the bleaching effect produced by any definite concentration. As at the Vallejo field, the calculated concentrations were checked from time to time by analyses.

On April 8 and 9 there was a considerable rainfall, so that on May 10, when the fumigations were started, the soil was moist, and in some parts of the field water was standing on the surface.

The plats at Davis (see Pl. XXV, *B*) are grouped under the following series:

Series 1.—Plats that were given one or two strong fumigations of sulphur dioxide, resulting in severe injury, then allowed to grow normally.

Series 2.—Plats that were subjected to fumigations of 10 minutes' duration daily during the season.

Series 3.—Plats that were subjected to an average of about four fumigations each of 5 minutes' duration nearly every day during the season regardless of humidity conditions.

Series 4.—Plats that were fumigated expressly for the purpose of determining "invisible" damage.

Series 5.—Plats that were given 5-minute fumigations at different times under lower humidity conditions than series 3.

Series 6.—Plats that were given 5-minute fumigations in the shade.

Series 7.—Plats that were given fumigations under different sunlight and shade conditions.

Series 8.—Plats fumigated in the open air outside the cabinets. In this series are also included the fumigations made under a cabinet when the air and the gas mixture were distributed throughout the cabinet by pipes.

EXPERIMENTS IN SERIES 1, DAVIS.

Plats 10, 11, and 26 were fumigated to produce a very severe bleach.

SUMMARY OF RESULTS OF EXPERIMENTS.

Plat 10 was fumigated when the plants were about 25 cm. high. Due no doubt to the high humidity, the injury produced was greater than had been produced by a similar fumigation at Vallejo. The effect of this severe bleach was to reduce the yield only slightly, the total weight of "grain and straw" per head being 4 per cent greater than the check and the yield of "grain" per head being 4 per cent less than the check.

Plat 11 was fumigated under low-humidity conditions two weeks later, when the grain was 38 cm. high and the sheath in evidence. This was not so severely bleached as No. 10. The yield from this plat was practically 7 per cent less than the check.

Plat 26 received a very severe bleach during the time the grain was "in the milk." At the front of the plat practically none of the foliage was left unbleached. Even the beards were bleached as far down as the glumes. In the back there was some green foliage left, probably about 30 per cent of the total. Even after this intensely severe bleach and killing of the foliage the plants matured grain, the yield in front being 80 per cent and in the back 81 per cent of the yield of the check.

The results from these plats bear out the results obtained at Vallejo, namely, that one or two severe bleaches in the early stages of the growth do not seriously affect the yield in grain. Fumigations made while the grain was "in the milk" caused a larger decrease, but the maximum decrease of yield was not more than 25 per cent. Some of the kernels were killed outright and others did not mature normally.

A. BARLEY FIELD AND FUMIGATION APPARATUS USED AT DAVIS, CAL.

B. SIZE AND ARRANGEMENT OF EXPERIMENTAL PLATS AT DAVIS, CAL.

Summary of results of experiments in series 1, Davis.

Plat No.	Concentration of SO_2.		Length of time of fumigation.	Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.			Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
			Hours.		*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
Check				407	2.95	1.19	4.58	26	100	100
10 (front)	5.0	0.0130	1	461	3.08	1.08	4.41	25	104	96
Check				517	3.02	1.14	4.83	24	100	100
11 (front)	3.0–5.0	.0069–.0130	3	567	2.88	1.04	3.94	26	95	91
Check				461	2.80	1.11	4.03	27	100	100
26 (front)	10.0	.0260	1	306	2.72	.63	3.22	20	97	80
26 (back)	5.0	.0130	1	423	2.69	.76	3.49	22	96	87

PLAT 10.

At the time of fumigation the plants in this plat were well stooled out and were about 25 cm. high. The soil was wet from rain of April 8.

Date of fumigation, April 10, 1914.

Time of fumigation, 1 hour.

Volume delivered to cabinet, 3.5 cubic meters per minute.

Volume SO_2 added, 17.5 c. c. per minute.

SO_2 calculated, parts per million, 5 (0.0131 gram per cubic meter).

SO_2 by analysis—at inlet, 4.8, and at outlet, 3.5 parts per million.

Temperature of the air in cabinet—at inlet, 21° C.; at outlet, 29° C.

Humidity of air in cabinet—at inlet, 60 per cent; at outlet, 80 per cent.

Notes.

April 11.—Very severe injury, the "concentrated" type, all over the plat. Many leaves almost completely bleached. About 60 per cent of the foliage affected. Worse injury in front than in back.

April 23.—Plants are growing as normal. Injury still showing over the whole plat. Most blades are white at their tip ends. Plants as high as in the check.

April 29.—Plants have been growing very rapidly. Now about 40 to 45 cm. high. Superficial examination would fail to show any signs of the bleach. Careful examination, however, reveals the presence of the old injury on the tips of the leaves. Also an abnormally large number of dried-up leaves around the base.

May 2.—No signs of bleach visible. Plants appear perfectly normal and as high as the check.

May 15.—In every way the plants in No. 10 look the same as in the check plats.

May 28.—Plat 10 appears normal in size. Heads appear to be filled out as in the check. Grain now starting to ripen.

June 15.—Ripe and cut. The check plat was not fumigated, but was simply staked off and allowed to grow normally.

PLAT 11.

Fumigated, April 26 and 27, 1914.

Height of plants, 35 to 40 cm.

On April 26 received a 1-hour fumigation of 3 parts sulphur dioxide per million parts of air by volume.

On April 27 received 1 hour's fumigation of 3 parts and 1 hour of 5 parts sulphur dioxide per million parts of air by volume.

No record of the temperature or humidity was made during the fumigations.

The injury on this plat developed very slowly; after the "mottled" type appeared, then in 24 hours the "concentrated" type was present.

Notes.

May 2.—Five days after fumigation. The injury was all the "concentrated" type and general all over the plat. About 60 per cent of foliage affected.

May 15.—At this date the injury was almost all outgrown. Now less than 10 per cent of foliage affected. Some of the "mottled" type of injury persists, but the general bleach is the "concentrated" type.

May 28.—No signs of the injury. Plants appear normal in every way.

June 15.—Ripe and cut.

The check for this plat did not receive any fumigations.

PLAT 26.

Fumigated on May 5 for a period of 90 minutes with 10 parts SO_2 per million parts of air by volume. At this time the plants in this plat were from 50 cm. to 60 cm. high, were headed out, and "in the milk." No temperature or humidity records were made during the fumigation.

Notes.

May 5.—Some of the leaves started to droop and wilt even before the cabinet was removed. In three hours after the fumigation the bleach had developed to about its maximum. The injury was extremely severe. In front practically 95 per cent of all foliage was bleached, with the "concentrated" type injury. Even the beards of the heads were bleached back to the glumes. The glumes themselves were not bleached but remained green. The back portion of the plat was not so badly affected as was the front, probably 60 per cent being bleached.

May 15.—The heads appear to be developing about as normally, though they are somewhat smaller than in the check plat. The foliage is not recovering.

May 28.—The heads are developing, but are undoubtedly smaller than in the check. The dried leaves in the plat are badly infected with a fungus disease, much worse than the check plat.

June 15.—Ripe and cut.

Two samples were taken. One from the front of the plat and one from the back end where the injury of May 5 was not as great as in the front.

Results of experiments in series 1, Davis.

[Strong fumigations of SO_2 and intense bleaching.]

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	1.12	1,341	456	442	97	527
10 (front)	1.12	1,588	516	500	97	542
Check	1.67	2,609	865	845	98	967
11 (front)	1.67	2,722	946	935	99	971
Check	1.12	1,446	516	502	97	560
26 (front)	1.12	933	343	338	98	213
26 (back)	1.12	1,272	473	470	99	358

EXPERIMENTS IN SERIES 2.

PLATS 1, 2, AND 3, WITH CHECK.

On 53 days of the 65 between April 10 and June 13, inclusive, each of these plats received one fumigation of 10 minutes' duration. Plats 1, 2, and 3 were fumigated, respectively, with concentrations of 5, 4, and 3 parts sulphur dioxide per million parts of air.

The average temperature of the air blown into the cabinets was 26° C., and the average temperature at the end of the 10-minute period at the outlet end was 33° C., a rise of 7° C. being brought about during the passage through the cabinet.

The relative humidity at the inlet was 51 per cent and at the outlet 60 per cent.

The maximum temperature at the inlet was 38° C., and at the outlet end 51° C.

The relative humidity at this time was 20 per cent at both ends.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

The visible injury caused by daily fumigations of 10 minutes each was very great and corresponded with that produced by similar treatment at the Vallejo field.

Due to the smaller volume blown through the cabinet and the larger mass of vegetation present, the absorption of the sulphur dioxide was greater here than in most of the Vallejo plats. Thus the difference in the injury produced in the front and back of the plats was greater at Davis than at Vallejo. The absorption of sulphur dioxide was about 40 per cent during the travel through the cabinet. Thus we found the same injury at the far end of No. 1, which received 5 parts SO_2 per million parts of air, that was found at the front part of No. 3, which received 3 parts SO_2 per million parts of air. With these facts in mind it is interesting to compare the yield in the several

parts that were noted as having the same general appearance throughout the season.

Summary of experiments in series 2, Davis.

[53 10-minute fumigations made.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check	.....	.....	477	2.64	1.10	4.19	26	100	100
3 (front)	3.0	0.0069	490	2.25	.89	3.69	24	95	81
3 (middle)	a 2.5	.....	447	2.43	1.12	4.06	28	92	102
3 (back)	a 2.0	.....	482	2.36	1.10	4.17	26	90	100
2 (front)	4.0	.0104	400	2.14	.85	3.45	25	81	77
2 (middle)	a 3.3	.....	374	2.22	.84	3.80	22	84	76
2 (back)	a 2.6	.....	390	2.23	1.07	3.84	28	84	97
1 (front)	5.0	.0130	423	1.79	.70	3.19	22	68	64
1 (middle)	a 4.0	.....	433	2.28	.82	3.35	25	86	75
1 (back)	a 3.0	.....	523	2.28	.89	3.77	24	86	81

a Approximate.

Average relative yields of entire plats.

Plat No.	Yield of straw and heads.	Yield of grain.
	Per cent.	*Per cent.*
Check	100	100
1	80	73
2	83	83
3	89	94

Comparison of yield from different parts of plats.

Plat No.	Part of plat.	Proportion of yield of check plat.	
		Heads and straw.	Grain.
		Per cent.	*Per cent.*
1	Middle	86	75
2	Front	81	77
1	Back	86	81
2	Middle	84	76
3	Front	85	81
2	Back	84	97
3	Middle	92	102

The back half of No. 3 showed only slight injury throughout the season and on the end gave a yield in "grain" about equal to the check.

Notes on plats 1, 2, and 3.

Grain 20 to 22 cm. high.

April 16, after five fumigations.—The first five fumigations have been made under relatively high humidity, that is, about 75 per cent. All plats show some injury.

Plat 1.—Shows a great deal of the "mottled" type injury. About 30 per cent of the foliage affected.

Plat 2.—Less affected, but showing injury of the "mottled" type.

Plat 3.—Still less affected, but also showing injury of the mottled type.

A question has arisen as to whether this injury is all sulphur dioxide bleach. Some of the mottling does not seem characteristic of sulphur dioxide.

April 18, after seven fumigations.—Appearance about the same as on April 16.

April 23, after 13 fumigations.

Plat 1.—Plants now about 30 cm. high and about the same height as No. 2 and No. 3 and the check. Injury now general over the whole plat, mostly the "mottled" type, but also some tips are bleached with the "concentrated" type. Undoubtedly some of the injury is due to bacterial disease. The youngest leaves the least affected and these show only the "mottled" type. Older leaves are more or less yellowish and dead at the tips.

Plat 2.—Injury generally all the "mottled" type. Larger proportion of dead leaves and yellowish leaves than in check plat. Part of injury probably due to some disease.

Plat 3.—Abnormal number of dried up and yellowish basal leaves. The injury on the green leaves all the fine "mottled" type. About one-half as bad as plat 2.

April 29, after 19 fumigations.

Plat 1.—Very few leaves that are not affected—either "killed back" or "mottled." Maximum height of plants, 42 cm.; minimum height of plants, 33 cm. Some difference in the injury showing at the front of the plat and at the back.

Plat 2.—Practically all leaves affected mostly with the "mottled" type of injury. Many dried-up basal leaves. Maximum height of grain 40 cm.; minimum 37 cm.

Plat 3.—Front of plat worse than back. Fine "mottled" type of injury. Grain is later than in No. 2. Maximum height is 45 cm.; minimum, 40 cm.

May 2, after 22 fumigations.—Grain now heading out very rapidly. In none of these plats do the heads look to be affected. The oldest leaves are nearly all dried up, though the youngest leaves are but slightly affected, the "mottled" type injury showing. A marked difference is now noted in the injury between the front and back of the plats. The back part of No. 1 looks about the same as the front part of No. 3. This difference bears out the analysis that the concentration at the back of No. 1 is only 3 parts SO_2 per million parts when the air blown in at the front carries 5 parts SO_2 per million parts of air.

May 7, after 26 fumigations.

Plat 1.—Now there is a very marked difference in appearance between the back and the front of the plat. The back third looks about the same as the middle of No. 2 or the front of No. 3. The grain is much shorter and has much smaller heads in front than in back. In front there is hardly a leaf that is not bleached. Even the sheath is "mottled." In the back part the new leaves are not affected, or only slightly so. Also there are not many old leaves in that part of the plat.

Plat 2.—In front this plat is about as the middle of No. 1, and the back is about as the middle of No. 3.

Plat 3.—The back of this plat is only slightly affected and the leaves here have only the "mottled" type injury. Heads over the plat are about normal size and well developed.

May 13, after 32 fumigations.

Plat 1.—Average plants about 40 cm. high in front and about 60 cm. high in back. Practically all foliage, even beards of heads, in front is bleached. Heads are not affected but are small and poorly developed in front. In back the heads are much larger and fuller and only 50 per cent of the foliage is bleached.

Plat 2.—Average plants about 50 cm. high in front and 65 cm. high at back. All leaves more or less "mottled" and beards also bleached. About 75 per cent of the foliage bleached or dead in front and about 35 per cent in back.

Plat 3.—Plants about 60 cm. high in front and 70 cm. high in back. Back of plat as high as check and not much leaf surface injured. Front is somewhat shorter than normal. The heads, however, appear normal. Some have mottling, due to bacterial disease.

May 28, after 42 fumigations.

Plat 1.—General appearance about the same as on preceding dates. No green foliage in front. Heads still green, but are very small and thin. Vegetation is greener and the heads are larger from front to back.

Plat 2.—Relative appearance of the grain in different parts of the plat the same as noted before. Heads appear about normal in size and development.

Plat 3:—Relative size of grain in the different parts of the plat is about the same as noted. Grain heads appear normal. No injury apparent in last third of plat.

June 17.—All the plats ripe and cut on this date. Each plat was divided into thirds and an area 1.12 square meters was cut out of each third as samples. Two check plats were cut. These plats had been allowed to grow normally and had received no fumigations of any character.

Results of experiments in series 2, Davis.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Average of checks	.....	1,410	534	520	97	572
1 (front)	1.12	848	475	466	98	326
1 (middle)	1.12	1,107	485	475	98	389
1 (back)	1.12	1,333	586	569	97	505
2 (front)	1.12	961	449	437	97	372
2 (middle)	1.12	930	418	404	97	339
2 (back)	1.12	993	437	437	100	468
3 (front)	1.12	1,247	554	541	98	480
3 (middle)	1.12	1,220	502	491	98	551
3 (back)	1.12	1,274	540	518	96	569

EXPERIMENTS IN SERIES 3.

PLATS 6, 7, 8, AND 9.

On 54 days between April 11 and June 13 these plats received a total of 199 fumigations, each of 5 minutes' duration. These fumigations were usually given four per day, with about an hour's interval between them.

Plats 6, 7, 8, and 9 received, respectively, fumigations of 1, 2, 3, and 4 parts SO_2 per million parts of air.

The average temperature of the air blown into the hood was 26° C., and the air at the outlet was 31° C. at the end of the 5-minute period. The average humidity of the air blown into the cabinet was 50 per cent, and at the outlet, at the end of 5 minutes, the average humidity was 57 per cent. The maximum temperature of ingoing air was 38° C., and of the air at the outlet 45° C.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

Plat 6, which received 1 part SO_2 per million parts air, was only slightly affected at any time. The injury on plats 7, 8, and 9 was similar to that produced on plats 32, 33, and 34, respectively, at

Vallejo. Plat 9, which received fumigations of 4 parts SO_2 per million, suffered very severely. In the latter part of the growth practically all foliage in the front part of this plat was bleached.

In these plats, as in plats 1, 2, and 3, the injury was considerably greater in the front than in the back portion of the plats. The grain yield for No. 6 was slightly greater than for the check plat. The other plats gave decreased yields in grain amounting to 10 per cent in the case of plat 7, 20 per cent in the case of plat 8, and 27 per cent in the case of plat 9.

Summary of experiments in series 3, Davis.

[199 5-minute fumigations.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check			400	2.97	1.12	4.37	26	100	100
6 (front)	1.0	0.0026	492	2.78	1.21	4.20	29	94	108
6 (middle)			412	2.82	1.20	4.29	28	95	107
6 (back)			433	2.52	1.10	4.45	25	85	98
7 (front)	2.0	.0052	423	2.21	.98	4.16	24	74	88
7 (middle)			503	2.11	.95	3.98	24	71	85
7 (back)	[a] 1.2		450	2.47	1.09	4.08	27	83	97
8 (front)	3.0	.0069	482	1.73	.72	3.71	19	58	64
8 (middle)			403	2.20	.96	3.97	24	74	86
8 (back)	[a] 2.0		381	2.15	1.00	4.02	25	72	89
9 (front)	4.0	.0104	271	1.68	.77	3.26	24	57	69
9 (middle)			310	1.79	.84	3.46	24	60	75
9 (back)	[a] 2.5		362	1.89	.85	3.98	21	64	76

[a] Approximate.

Average relative yields of entire plats.

Plat No.	Yield of straw and heads.	Yield of grain.
	Per cent.	*Per cent.*
Check	100	100
6	91	104
7	76	90
8	68	80
9	60	73

The total weight of "heads and straw" was in all cases less than the check, in the case of plat 9 the yield being only 60 per cent that of the check.

Notes.

April 13.—Nine fumigations under high humidity conditions; average 65 to 70 per cent.

Plat 6.—No injury visible.

Plat 7.—Very faint spotting of a few leaves in front.

Plat 8.—"Mottling" of leaves over plat, especially in front.

Plat 9.—General "mottling" of leaves all over plat.

April 16.—Twenty-one fumigations.

Plat 6.—No injury visible.

Plat 7.—Slight "mottling" over the front of the plat.

Plat 8.—Increase of "mottled" area over that of April 13.

Plat 9.—General "mottled" injury, with some indications of the "concentrated" type.

April 23.—Fifty-one fumigations. Plants at this time about 36 cm. high.

Plat 6.—At this date a few slight traces of "mottling" and tip injury noted in front.

Plat 7.—Slight injury of the "mottled" type over the whole plat.

Plat 8.—Three or four times as much injury to No. 8 as to No. 7. "Mottled" type injury.

Plat 9.—Injury appears about three times as great as in plat 8. Some "mottled" type, but generally the white "concentrated" type.

April 29.—Seventy-six fumigations.

General appearance of the plats about the same as on the 23d.

Plat 6.—Shows slight injury only on a few leaves in front.

Plat 9.—Looks about the same as does plat 1.

May 2.—Eighty-three fumigations.

Grain now just starting to head out. Plants in plat 9 are shorter than the plants in plats 6, 7, 8, or the check. The damage is evidently worse than in plat 1.

May 7.—One hundred and one fumigations.

Plat 6.—Shows very few leaves slightly "mottled." Grain is of good height, about the same as check, except in the back, where it is about 10 cm. taller and is well headed out.

Plat 7.—Many slightly "mottled" leaves in front; only a few in the back. Plants are tall as normal and well headed.

Plat 8.—Badly injured in front; about 60 per cent of foliage is bleached at that part. Less injured at the back. Front averages about 5 cm. shorter than back. Heads are not bleached and appear about normal.

Plat 9.—Marked difference between front and back portions of plat. Very severe injury in front, practically all foliage is bleached. Heads are green, but are smaller than normal. Injury decreases from front to back. Back now looks as does the front of plat 8.

May 13.—One hundred and twenty-five fumigations.

Plat 6.—As on the 7th. Plants about normal height—that is, about 55 to 70 cm. tall. Shows only very slight injury.

Plat 7.—Plants normal height. Slight injury in front. Heads appear all right.

Plat 8.—"Mottled" type injury general all over the plat, the amount decreasing from front to back. About half of foliage affected. Plants in front are smaller than normal.

Plat 9.—Very severe injury all over the plat. Only youngest leaves retain any green color. About four-fifths of all foliage is bleached white and "mottled." Plants are much shorter than the check. Heads are decidedly shorter and less developed.

May 28.—One hundred and fifty-nine fumigations.

Plat 6.—Plants are normal in height in front and heads are well developed. Average height, 65 cm. Except for abnormally large number of dried basal leaves, no sign of injury evident. In back, the plants are shorter than in front, due to natural growth.

Plat 7.—Average height, 60 cm. A few traces of sulphur dioxide mottling now evident. Heads appear slightly smaller than in check or in No. 6.

Plat 8.—Average height of plants 60 cm. Not much shorter than in plat 7. Heads appear slightly smaller than in plat 7.

Plat 9.—Reduced growth and slight delay in ripening now very evident. Average height about 55 cm., and only about 45 to 50 cm. in front. On the few remaining

green leaves much "mottling" is evident. Plat still shows decided decrease in visible injury from front to back. Heads are much smaller than normal.

June 17.—All plats were ripe and ready to cut on this date. Plat divided into thirds and samples of 1.12 square meters area were taken from each, as in the case of plats 1, 2, and 3.

Results of experiments in series 3, Davis.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Average of checks	.....	1,332	448	431	96	485
6 (front)	1.12	1,529	551	533	97	646
6 (middle)	1.12	1,302	461	455	99	547
6 (back) [a]	1.12	1,218	484	473	98	519
7 (front)	1.12	1,046	473	462	98	451
7 (middle)	1.12	1,187	563	549	97	524
7 (back)	1.12	1,246	504	490	97	534
8 (front)	1.12	933	540	526	97	379
8 (middle)	1.12	992	451	436	97	417
8 (back)	1.12	920	427	420	98	422
9 (front)	1.12	508	303	293	97	225
9 (middle)	1.12	622	347	337	97	283
9 (back)	1.12	766	405	400	99	339

[a] Grain in this part of plat shorter, due to natural causes.

EXPERIMENTS IN SERIES 4.

The plats in this series were fumigated to determine the possibility of "invisible" injury. They were fumigated from time to time to the point of showing a slight visible bleach.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

Plats 4 and 5 comprise this series. These plats were given 10-minute fumigations of 1 and 2 parts SO_2 per million parts of air, by volume, respectively, until bleaching began to be quite severe on plat 5, then fumigation stopped for several days and the plants were allowed to recover before fumigations were resumed. Between April 11 and 23, inclusive, these plats received 46 10-minute fumigations. No fumigations were made on these plats then until May 4. Then 20 fumigations were given between May 4 and 18, inclusive. Fumigations resumed on May 28 and continued to June 12, during which time 12 fumigations were made. Thus, total fumigations equal 78.

The average temperature of the air blown into the cabinet was 27° C. The average temperature of the air at the back of the cabinet at the end of the 10-minute periods was 30° C. The average relative humidity of ingoing air was 55 per cent and of the outgoing air at end of 10-minute periods was 65 per cent.

The yield from these plats averaged 5 per cent greater than the yield from the checks, both in regard to the total weight of "straw and heads" and in regard to the "grain" yield. It was thought that this slight increase might be due to a "hothouse" effect in the cabinet during the fumigations; however, as will be shown in a table

given below it was found by experiments that the "hothouse" effect in 10-minute fumigations did not influence the yield, and thereby did not offset any "invisible" injury that might have been incurred. Thus, it must be concluded from these experiments on "invisible injury" that such injury does not exist. If grain is kept just partly bleached during the growing season and still yields a normal crop, the "invisible" injury is not appreciable or is nonexistent.

Summary of results of experiments in series 4, Davis.

[78 10-minute fumigations for "invisible-injury" data.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Check	.....	.....	518	2.64	1.10	4.19	26	100	100
4 (front)	1.0	0.0026	563	2.34	1.11	4.33	25	89	101
4 (back)	1.0	.....	474	2.72	1.22	4.00	30	103	111
5 (front)	2.0	.0052	505	3.06	1.15	4.22	27	116	105
5 (back)	2.0	.....	539	2.77	1.15	4.24	27	105	105

Notes.

April 16.—Seventeen fumigations.

Plat 4.—No visible damage.

Plat 5.—Slight "mottling" appeared on the plat near the front.

April 23.—Forty-six fumigations.

Plat 4.—Very slight "mottling" appears on some leaves near the inlet. None at the back end.

Plat 5.—"Mottled" type injury general over the whole plat. Injury about 5 to 8 per cent. Older leaves most affected.

April 28.—No fumigations since April 23.

Plat 4.—No signs of injury are visible.

Plat 5.—Old injury still visible, but appearance of plants much better than on April 23.

May 2.—

Plat 4.—Free from injury.

Plat 5.—Almost free from injury except many dead leaves around base; more than normally.

May 4.—Fumigations resumed. Grain now heading out.

May 13.—Fifty-nine fumigations. Well headed out and heads of good size; "in milk."

Plat 4.—No visible injury.

Plat 5.—Slight damage on a few leaves in front, and none in the back.

May 18.—Sixty-six fumigations.

Plat 4.—Suspicion of injury showing on this plat.

Plat 5.—Considerable bleaching all over this plat, about 15 per cent, of the "mottled" type.

Fumigations ceased temporarily.

May 28.—No fumigations since the 18th.

Plat 4.—No injury showing. Youngest leaves are green, oldest are pretty well dried up. Appearance normal.

Plat 5.—Not so near ripe as No. 4. No injury to present green leaves. Older leaves are dried up. Grain now in "dough" and beginning to ripen.

Fumigations resumed.

June 12.—Seventy-eight fumigations.

Fumigations continued up to time all grain ripe. As all foliage is dried up at this time, it is impossible to determine whether any injury was done to that portion of plant. Grain itself looks normal on both; large heads and well filled out.

Cut on June 17.

Area, 1.12 square meters.

Results of series 4, Davis, "invisible damage" determinations.

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Check	1.12	1,529	580	560	96	615
4 (front)	1.12	1,478	632	620	98	602
4 (back)	1.12	1,446	532	512	96	624
5 (front)	1.12	1,728	565	560	99	647
5 (back)	1.12	1,673	604	588	97	679

EXPERIMENTS IN SERIES 5.

This series consists of plats 16, 17, 18, and 19. These plats were given fumigations at times when the humidity of the air was less than 50 per cent. The length of each fumigation was five minutes. Plats 16 to 19 received, respectively, 1 to 4 parts SO_2 per million parts of air by volume in each fumigation. The fumigations were given on the following dates:

Date.	Number of fumigations.
Apr. 17	2
19	1
20	2
28	2
29	1
30	4
May 6	4
7	4
9	3
11	3
12	3
13	2
27	2
28	2
30	2
June 2	4
3	2
8	4
9	4
10	2
12	2
13	4
	59

The average temperature of the air blown into the cabinet was 28° C., and the relative humidity was 40 per cent.

The average temperature of the air at the far end of the cabinet at the end of the 5-minute periods was 32° C., and the humidity 50 per cent.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

A decrease was noted in the extent of the injury produced by fumigations under low humidity conditions, compared with the injury produced by an equal number of similar fumigations under higher humidity conditions. However, as these plats were not fumigated as frequently on as many successive days, a more definite comparison with the results obtained in series 3 can not be made.

A rough estimate of the relative injury produced by series 3 and 5 would be that in series 5 under lower humidities (average 55 per cent) the average injury per fumigation was three-fourths of that produced in series 3 under the high humidity (70 per cent) which prevailed during the first week that these plats were fumigated.

Summary of results of experiments in series 5, Davis.

[50 5-minute fumigations under comparatively low humidity conditions.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
16	1.0	0.0026	320	3.39	1.74	4.84	36	100	100
17	2.0	.0052	237	3.37	1.44	4.59	31	100	83
18	3.0	.0078	381	3.00	1.04	4.35	24	89	60
19	4.0	.0104	294	2.27	1.43	4.59	31	67	82

Notes.

April 23.—Five fumigations.

Plat 16.—No visible injury.

Plat 17.—No visible injury. Some yellowing of a few leaves.

Plat 18.—Fine "mottling" on a few scattered leaves over the plat.

Plat 19.—About 10 per cent of foliage affected by the fine yellow "mottled" type bleaching.

April 29.—Eight fumigations total—5 before April 20 and 3 subsequent.

Plat 16.—No signs of injury. Plants are higher in front than in back.

Plat 17.—No signs of injury. Plants are lower in front than in back.

Plat 18.—Few traces of old injury, but none of new.

Plat 19.—Traces of old injury apparent, also slight "mottling" caused by the three recent fumigations.

May 2.—Twelve fumigations.

Plats 16 and 17.—Show no signs of damage.

Plat 18.—Shows some slight signs of recent "mottling."

Plat 19.—"Mottling" caused by recent fumigations very evident.

May 7.—Twenty fumigations.

Plat 16.—No injury whatever.

Plat 17.—Shows very slight "mottling."

Plat 18.—Quite "mottled" in front, looks about as plat 7 front. Only slight injury to back of plat.

Plat 19.—Is quite injured in front, but only slightly, like No. 17 in back.

May 13.—Thirty-one fumigations.

Plat 16.—No injury visible except abnormal number of dead basal leaves present.

Plat 17.—"Mottled" leaves showing at front. None at back. Otherwise plat looks normal.

Plat 18.—About one-fourth of all leaves in front are mottled. Only a few in back. Plants look normal size.

Plat 19.—About half of all leaves in front of plat affected, "mottled" type injury. Only 10 per cent or so affected in back.

No fumigations on May 13 to 27 because humidity usually was too high.

May 28.—Thirty-three fumigations.

Plants in these plats are very uneven and in some places are especially tall and rank. Will be difficult to get conservative quantitative data concerning the weight of straw.

Plat 16.—No injury visible.

Plat 17.—No traces of previous injury apparent. Plants appear normal in size. Heads well filled out.

Plat 18—A few traces of previous injury showing. Otherwise the plants look perfectly normal.

Plat 19.—Only few traces of previous "mottled" injury. Many dead leaves. Plants appear about normal though heads are not quite so ripe as in plats 16 and 17.

Fumigations were kept up during the ripening period.

June 13.—Fifty-nine fumigations.

Grain now ripe. All foliage is dry. With exception of heads in the front of plat 19 the heads are apparently normal.

June 17.—The advisability of trying to get any quantitative data from this series of plats was doubtful. No satisfactory check plat could be found, for the plats were very variable in character.

Plat 16.—Was higher in front than in back.

Plat 17.—Was higher in back than in front.

Plat 18.—Was lower in the middle than at the ends.

Plat 19.—Was comparatively lower throughout compared with plats 16, 17, and 18,

All the plats were cut.

Area, 2.8 square meters.

Results of experiments in series 5, Davis.

[59 5-minute fumigations under comparatively low humidity conditions.]

Plat No.[a]	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Sq. meters.	*Grams.*			*Per cent.*	*Grams.*
16	2.8	3,034	895	882	98	1,537
17	2.8	2,240	664	650	98	936
18	2.8	3,203	1,067	1,035	97	1,078
19	2.8	1,868	822	810	99	1,160

[a] No satisfactory check plat could be found for this series. As shown by the number of heads and weight of straw per square meter, these plats were very uneven and dissimilar. Thus, a comparison of the yields of these plats is of very little value.

EXPERIMENTS IN SERIES 6.

The experiments in this series consisted of plats Nos. 20, 21, and 22.

These plats were fumigated for periods of 5 minutes, 42 times between April 29 and May 13, average three times per day, when the grain was heading and "in the milk" stage. The plats were shaded during the fumigations to determine the extent of injury in comparison with the injury produced in sunlight. Plats 20 to 22 received, respectively, concentrations of 2, 3, and 4 parts of SO_2 per million parts of air by volume.

The average temperature at the inlet was 26° C., and at the back end of the cabinet at the end of the 5-minute periods was 28° C. The average humidity at the inlet was 50 per cent and at the outlet 55 per cent.

SUMMARY OF RESULTS OF EXPERIMENTS IN THE SERIES.

The fumigations in the shade with 2, 3, and 4 parts SO_2 per million on plats 20, 21, and 22, respectively, did not produce as much visible damage to the foliage as did an equal number of similar fumigations in the sun on plats 7, 8, and 9. The difference, however, was not so great as that noted between the results of series 3 and series 5, where injury under high and low humidity conditions were compared.

As the fumigations of series 6 were made when the grain was heading out and was "in the milk" it was decided to obtain quantitative data concerning the effect on the yield of these fumigations. Two check plats were cut and their yield averaged for comparison.

In this series there was a gradual decrease in the total weight of the straw and heads per head from plats 20 to 22 amounting to 20 per cent in the case of No. 22. The yield of grain from plat 20 was the same as the check. The yield of grain per head from plat 21 was only 70 per cent and from plat 22, 86 per cent. This anomaly might be explained to a certain extent by the natural unevenness of the grain in the several plats.

Summary of results of experiments in series 6, Davis.

[42 5-minute fumigations in the shade.]

Plat No.	Concentration of SO_2.		Average number of heads per square meter.	Weight of—			Number of kernels per head.	Relative yield based on—	
	Parts per million.	Grams per cubic meter.		Heads and straw per unit head.	Grain per good head.	100 kernels.		Heads and straw.	Grain.
				Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*
Average check	.....	.....	408	2.95	1.23	4.58	27	100	100
20	2	0.0052	365	2.78	1.23	4.93	25	94	100
21	3	.0078	364	2.58	.86	4.19	20	87	70
22	4	.0104	266	2.32	1.06	4.29	25	79	86

Notes.

May 2.—Twelve fumigations.

Plat 20.—No injury visible.

Plat 21.—Slight "mottling" showing.

Plat 22.—Considerable "mottling" beginning to show. On the older leaves the tips are bleached back.

May 7.—Twenty-three fumigations.

Plat 20.—Very faint "mottling" appearing.

Plat 21.—"Mottled" over whole plat.

Plat 22.—Very decided "mottled" appearance all over the plat. About 30 per cent of foliage affected.

May 13.—Forty-two fumigations. Grain well headed out.

Plat 20.—Shows some minute traces of the yellowish "mottle" type bleach.

Plat 21.—About 15 to 20 per cent of foliage in front "mottled." Less in back.

Plat 22.—Injury general all over this plat. About 70 per cent in front and 41 per cent in back. "Mottled" type injury predominates. Some "concentrated kill-back" type. The plants in the plat are smaller and thinner than the normal, due to a great extent to natural causes.

May 28.—Fifteen days after last fumigations.

Plat 20.—No signs of injury are present except larger proportions of dead basal leaves than normal. Otherwise normal.

Plat 21.—Very few signs of sulphur-dioxide bleach. Many dried dead leaves.

Plat 22.—Traces of old injury still visible. This grain is not so ripe as plat 20, 21, or the check plat. Heads are smaller and not so well filled out. Grain smaller, partly due to natural causes.

June 17.—Grain ripe and cut on this date.

Whole plats sampled 2.8 square meters; strip taken down through the center.

Results of experiments in series 6, Davis.

[Forty-two 5-minute fumigations in shade.]

Plat No.	Area sampled.	Total weight of straw and heads.	Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.
	Square meters.	*Grams.*			*Per cent.*	*Grams.*
Average check					97	
20	2.8	2,833	1,021	1,007	99	1,240
21	2.8	2,636	1,020	990	98	849
22	2.8	1,729	745	724	97	767

EXPERIMENTS IN SERIES 7.

In series 7 the effect of sunlight and shade compared with the effect of high and low humidity on the susceptibility of grain to sulphur dioxide was studied. The results are given below.

PLATS 12 AND 13.

Plats 12 and 13 were run for comparison purposes with concentrations of two parts of SO_2 per million parts of air, by volume. Plat 12 was fumigated in the early morning hours when the dew was going off and before the sun was very high.

Plats 13 was fumigated in the late afternoon, when the vegetation was perfectly dry and the sun was relatively low in the west.

Plat 12.—Between April 13 and 25 had eleven 15-minute fumigations.

Average temperature of air in cabinet—inlet, 21° C.; outlet, 21° C.

Average humidity of air in cabinet—inlet, 65 per cent; outlet, 78 per cent.

Plat 13.—Between April 12 and 24 had eleven 15-minute fumigations.

Average temperature of air in cabinet—inlet, 23° C.; outlet, 26° C.

Average humidity of air in cabinet—inlet, 58 per cent; outlet, 64 per cent.

The injury to plat 12 was somewhat greater than to No. 13. After the fourth fumigation to No. 12 "mottled" type bleaching appeared, especially in the smaller plants and on the oldest leaves.

Not until after the sixth fumigation on plat 13 did the "mottling" appear.

On April 23, after No. 12 had had 10 fumigations and No. 13 had had 11, No. 12 was worse injured than No. 13 by about 25 per cent. The injury to both of these plats was decidedly greater per fumigation than to plat 17, fumigated under lower humidity conditions.

The recovery of these plats was rapid. By May 13 neither plat had any visible remains of the old injury.

PLATS 14 AND 15.

Each of these plats was fumigated for one hour on April 18 with 5 parts SO_2 per million parts of air by volume, or 0.013 gram of SO_2 per cubic meter.

Plat 14.—This plat was fumigated in the sunlight.

Average temperature of air in cabinet—inlet, 26° C.; outlet, 30° C.

Average humidity of air in cabinet—inlet, 56 per cent; outlet, 52 per cent.

Plat 15.—This plat was fumigated in the shade.

Average temperature of air in cabinet—inlet, 26° C.; outlet, 28° C.

Average humidity of air in cabinet—inlet, 56 per cent; outlet, 60 per cent.

Notes.

May 23.—Very severe injury on both plats. All injury was principally of the "concentrated" kill-back type. Injury was only slightly greater on plat 15 than on plat 14—less than 10 per cent difference.

These tests show that the humidity conditions are of greater influence than sunlight or shade in influencing the susceptibility of the plants to sulphur dioxide.

EXPERIMENTS IN SERIES 8.

Even in the 5-minute fumigations at Davis there was usually an increase in temperature and humidity at the far end of the cabinet

before the end of the fumigation period. At the inlet end, however, where the greatest injury on any plat was produced, the temperature and humidity conditions were the same or nearly the same as for the outside air. Although it is improbable that at the inlet end there could have been any abnormal conditions present to vitiate our results, it was decided to try to duplicate some of the fumigations in the open air outside any cabinet to determine whether materially different results would be obainted.

The first attempts along this line were to discharge the mixture of air and sulphur dioxide directly into the atmosphere over a plant or row of plants. However, only the first or first two plants directly in the line of the discharge pipe received the calculated concentration. Diffusion or dispersion takes place so rapidly that the concentration of the sulphur dioxide at a point only a short distance away from the discharge pipe was much lower than the calculated. The concentration at any point was variable, depending on the wind conditions. In the several experiments carried out with this method of fumigations the plants directly in front of the delivery pipe showed about the same extent of injury as was brought about by fumigation in the cabinet under the same humidity conditions.

In order to increase the number of plants that would be so fumigated the fumigation mixture was discharged into a galvanized iron pipe shaped as a Y; from the two upper ends of this Y extended galvanized iron pipes 80 cm. in diameter and 610 cm. long. Along this pipe were cut holes 2.54 cm. in diameter and 7.6 cm. centers, through which the air mixture was discharged. The two parallel perforated pipes extending from the Y were about 15 cm. apart, which allowed their being set down on either side of a row of barley plants. By this method of conducting the air-gas mixture to the plants it was thought to be possible to surround the plants in the row with the desired mixture. This was found to be an improvement over the method of blowing directly from the fan, but still did not give the desired results.

On several tests the pipes were laid on the ground, the holes uppermost, and the air was discharged directly upward. Analysis of the air in the center of the space between the pipes—that is, between the leaves of the plants—averaged only 50 per cent of the calculated concentration. The leaves that extended out over the holes and so received the calculated concentration were affected in about the same manner and to the same extent as they were when fumigated in the cabinet.

In another series of tests the pipes were supported about 40 cm. from the ground and the pipes turned so that the air streams were discharged converging toward a point near the center of the plants. In this series the analysis of the air surrounding the plants showed

that the concentration approached more nearly the calculated strength. In this series the injury sustained by the plants in the direct line of the discharge was found to be approximately the same as that sustained by plants when treated with the same concentration in our cabinet. Tests were made with concentrations of 3, 5, and 10 parts per million.

Another series of tests was made in which a cabinet was placed over a plat and the air-gas mixture was distributed by the pipes described above. No materially different results were obtained than from those obtained by the usual fumigations under the cabinet, except that the injury to the vegetation was more even over the plat.

From these tests the conclusions were arrived at that except for the rise in temperature and humidity at the far end of the cabinet, no abnormal conditions were present in the cabinet fumigations which affected the susceptibility of the plants to such an extent as to influence the results.

SUMMARY OF ALL DATA CONCERNING "INVISIBLE" INJURY TO PLANTS.

The following table has been prepared to show the data obtained from all the plats that received fumigations to the extent of a very slight bleach or visible injury during the whole or a large portion of the growing season. In this table are included the data from the plats that were carried through expressly for the "invisible" injury data, namely, Vallejo plats 26 and 44 and Davis plats 4 and 5.

The data from the plats that were slightly bleached during the season are also given, namely, Vallejo plats 14, 31, and 37 and Davis plats 6 and 20.

From the data of these plats it is to be concluded that no "invisible" injury affected the growth or the fruiting of the grain, and that for a grain crop like barley, the possibility of such "invisible" injury taking place to an appreciable extent is very remote.

Summary of results of all experiments to determine "invisible" injury.

[Number of plats from which data were obtained, 9.]

Plat.	Average weight of—	
	Heads and straw per unit head.	Grain per good head.
	Grams.	*Grams.*
Fumigated[a]	2.80	1.33
Check	2.81	1.29

[a] Relative yield based on "heads and straw," 100 per cent; based on "grain," 103 per cent.

Summary of all data concerning experiments to determine "invisible" injury.

Plat No.	Concentration of SO_2		Length of time of each fumigation.	Number of fumigations.	Period during which fumigations were made.	Weight of—				Comparative yield based on—	
	Parts per million.	Grams per cubic meter.				Heads and straw per unit head.		Grain per head.		Heads and straw.	Grain.
						Plat.	Check.	Plat.	Check.		
Vallejo.			*Minutes.*							*Per cent.*	*Per cent.*
14	1.0	0.0026	10	90	Mar. 26 to June 13	2.42	2.43	1.24	1.28	100	97
26	.5	.0013	60	29	Mar. 31 to Apr. 15	2.52	2.95	1.30	1.22	85	106
31	1.0	.0026	5	186	Apr. 1 to June 12	3.00	2.56	1.51	1.31	117	115
37	1.0	.0026	5	33	Apr. 6 to Apr. 16	2.91	3.07	1.64	1.68	95	98
44	.5	.0013	60	62	Apr. 15 to June 12	3.44	3.11	1.54	1.55	111	100
Davis.											
4	1.0	.0026	10	78	Apr. 11 to June 12	2.53	2.64	1.16	1.10	96	105
5	2.0	.0058	10	78	do	2.92	2.64	1.15	1.10	110	105
6	1.0	.0026	5	199	do	2.71	2.97	1.17	1.12	91	105
20	2.0	.0058	5	42	Apr. 29 to May 13	2.78	2.95	1.23	1.23	94	100

COMPARISON OF YIELDS OF CHECK PLATS.

The following figures show the comparative yields of three check plats taken side by side.

Plat 1 was allowed to grow normally.

Plats 2 and 3 were each fumigated 56 times for periods of five minutes with air containing no sulphur dioxide.

At no time was there any injury on the fumigated checks or any abnormal leaf-markings present on the checks that were fumigated, which were not also present on the unfumigated checks. Thus, no visible injury or markings that resembled sulphur dioxide injury were present on the leaves of the fumigated plats.

A comparison of their quantitative yields is given below:

Comparison of yields of check plats.

[Plat 1 was not fumigated; plats 2 and 3 were each fumigated 56 times for periods of 5 minutes with air containing no SO_2.]

Plat No.	Weight of heads and straw.		Total number of heads.	Number of good heads.	Proportion of total.	Total weight of grain.	Weight of grain per good head.	Weight of grain per 100 grains.	Number of grains per head.	Relative yield based on—	
	Total weight.	Weight per head.								Heads and straw.	Grain.
	Grams.	*Grams.*			*Per ct.*	*Grams.*	*Grams.*	*Grams.*		*Per ct.*	*Per ct.*
1	1,406	2.96	475	460	97	582	1.26	4.54	28	100	100
2	1,529	3.03	524	508	97	615	1.21	4.53	27	102	100
3	1,047	2.85	368	360	98	439	1.22	4.67	26	96	103

EFFECT OF FUMIGATION UPON DISEASES OF PLANTS.

In the Vallejo field during May there developed, in a great many spots, a yellowing of the foliage of the grain. In fact, the yellowing was pretty general all over the field, and when referred to the plant pathologists was found to be due to a fungus disease. There is very little doubt that part of the yellow bleaching noted during April, in plats 31 to 35 and 17 and 18, which received 5 and 10 minute fumigations, was due to this disease. That being the case, the evidence would seem to point to the conclusion that the plants were rendered especially susceptible to the disease by the continued short-time fumigations. However, none of the plats that were severely bleached once or twice had an abnormal number of the yellowish leaves.

At Davis, plat 26 received a very severe fumigation and severe bleach appeared. At the end of the season the old bleached leaves in this plat appeared to be severely attacked by a fungus disease—"Helminthsporium"[a]—none more so than the check. On the other plats, however, no appreciable difference was noted in the extent of this disease between fumigated and check plats.

In general the fumigated plats had a smaller percentage of moldy heads.

Comparison of percentage of good heads to total heads.

Series No.	Proportion of good heads to total heads.		Series No.	Proportion of good heads to total heads.	
	Check plat.	Fumigated plat.		Check plat.	Fumigated plat.
Vallejo experiments.	*Per cent.*	*Per cent.*	*Davis experiments.*	*Per cent.*	*Per cent.*
1a and 1b	89	90	1	97	99
1c	81	93	2	97	98
2	83	92	3	96	97
3	88	89	4	96	97
4	86	85	5	98	98
5	89	88	6	97	98
6	84	87			
7	91	93			
9a	81	88			
Average	86	89	Average	97	98

[a] Sulphur trioxide used in this series.

It is noted that plats 1c, 2, and 9, which received comparatively strong fumigation while the heads were filling out, had the greatest difference in percentage of good heads between plats and check.

The relative yield of the grain from the fumigated and check plats was based on the average weight of grain per good head. However, as the percentage of good heads to the total was greater in the case of the check plats, by basing the yield of grain on the weight per unit total head the figures for the fumigated plats would be slightly increased. However, those from series 1c and series 2 are the only figures that would be seriously affected by the change.

[a] Dr. Blankinship's identification.

DETERMINATION OF SULPHUR IN THE PLANT FOLIAGE.

In connection with the investigation of injury to growing barley by sulphur dioxide, it was considered important to determine whether the plants subjected to the action of sulphur dioxide showed an increase in the amount of sulphur present in the foliage and grain kernels above that found in plants not subjected to the gas.

METHOD OF SAMPLING.

When the barley had been cut and weighed, samples of the dried leaves were taken for the determination of their sulphur content. About 30 grams of the leaves was taken from each sample. In the laboratory the foliage was cut into pieces less than 2.5 cm. long, and the size of each sample was reduced from 25 to 10 grams. These 10-gram samples were dried at 95° C. for 48 hours and then ground to a fine powder in a drug mill. This powder was placed in a small weighing bottle and dried at 95° C. for 24 hours.

METHOD OF ANALYSIS.

The method employed in these analyses was essentially the fusion method described in Bulletin 107, Bureau of Chemistry, United States Department of Agriculture.

The analyses were made by Mr. G. C. Bartells and Mr. C. E. Brandt in the laboratory of Gould, Free & Ash.

One gram of the dried powder was transferred to a nickel crucible of 250-c. c. capacity, 2 c. c. of water and 5 grams of sodium carbonate were added, and the mixture was stirred carefully. Five grams of sodium peroxide was added in small amounts and well stirred in with the rest of the mixture.

The crucible was then placed in a small specially designed electric furnace of the resistance type and the material fused down slowly. Small amounts of sodium peroxide were added and the crucible rotated until the fusion was perfect. The crucible was kept at the fusion temperature for about 10 minutes and then cooled. It was then covered with a watch glass, 100 c. c. of water was added by a pipette, and the crucible was placed on an electric hot plate to effect solution.

The resulting solution was washed into a No. 5 Jena beaker, hydrochloric acid in excess was added slowly by a fine capillary pipette, and the solution was evaporated to dryness on the hot plate. After dehydration the soluble salts were dissolved in 5 c. c. HCl and 150 c. c. H_2O, and the solution was heated and filtered.

The filtrate and washings were diluted to 350 c. c. and cooled. Then 10 c. c. of 5 per cent $BaCl_2$ was added very slowly through a small-bore tube and without stirring. The solution was then allowed

to stand 48 hours, when it was filtered through a weighed Gooch crucible, washed with water and then with alcohol-ether, dried for 2 hours at 120° C., and then weighed.

Samples of barley kernels were ground to a powder, sampled, dried, and analyzed, as were the foliage samples.

Results of analyses to determine sulphur in plant foliage, Vallejo samples.

Plat No.	SO_2 treatment.	Sulphur content.	
		In foliage.	In kernels.
		Per cent.	*Per cent.*
Check		0.34	
9	1 part SO_2 per million for 43 hours during early growth	.45	
Check		.49	0.15
22	2 1-hour fumigations of 10 parts SO_2 per million during early growth	.57	.26
Check		.36	
74	35 2-minute fumigations of 5 parts SO_2 per million	.40	
Check		.38	
46	3 1-hour fumigations of 5 parts SO_2 per million	.52	
20		.41	
21	90 60-minute fumigations with 1 part SO_2 per million	.56	
12	181 30-minute fumigations with 1 part SO_2 per million	.64	
Check		.46	
7	198 15-minute fumigations with 2 parts SO_2 per million	.62	

Results of other sulphur determinations, Vallejo samples.

SAMPLES FROM SERIES 2.

[Ninety 10-minute fumigations.]

Plat No.	SO_2 treatment—parts per million.	Proportion of sulphur.	
		In foliage.	In grain.
		Per cent.	*Per cent.*
Check	0	0.43	0.17
14	1.0	.43	.15
15	2.0	.47	.18
16	3.0	.55	.24
17	4.0	.75	.26
18	5.0	.82	.25

SAMPLES FROM SERIES 3.

[One hundred and eighty-six 5-minute fumigations.]

Check	0	0.47	No analysis.
31	1.0	.48	Do.
32	2.0	.50	Do.
33	3.0	.53	Do.
34	4.0	.59	Do.
35	5.0	.65	Do.

SAMPLES FROM SERIES 4.

[Thirty-three 5-minute fumigations.]

Check	0	0.43	No analysis.
37	1.0	.47	Do.
38	2.0	.49	Do.
40	3.0	.43	Do.
41	4.0	.49	Do.
42	5.0	.45	Do.

The following figures, showing the sulphur content of foliage subjected to severe fumigation with sulphur trioxide fume, are of special interest:

Results of experiments in which foliage was subjected to severe fumigation with SO_3.

Plat No.	Character of sulphur trioxide fumigation.	Proportion of sulphur.	
		In foliage.	In kernels.
		Per cent.	*Per cent.*
Check		0.52	0.14
80	0.015 gram per cubic meter—2-hour fumigation	.52	.13
82	0.018 gram per cubic meter—1-hour fumigation	.54	.14
89	0.021 gram per cubic meter—2½-hour fumigation	.52	.14

Results of analyses to determine sulphur in plant foliage, Davis samples.

SERIES 1.

Plat No.	SO_2 treatment.	Sulphur content.	
		In foliage.	In kernels.
		Per cent.	*Per cent.*
Check		0.18	0.19
11	5 parts SO_2 per million for 1 hour during early growth	.24	.19
Check		.15	.14
26	10 parts SO_2 per million for 1½ hours, when grain headed out	.27	.18

SERIES 2.

[Fifty-three fumigations of 10 minutes each.]

Check		0.22	0.16
3	3 parts SO_2 per million	.41	.18
2	4 parts SO_2 per million	.43	.19
1	5 parts SO_2 per million	.47	.20

SERIES 3.

[One hundred and ninety-nine fumigations of 5 minutes each.]

Check		0.18	0.16
6	1 part SO_2 per million	.26	.19
7	2 parts SO_2 per million	.34	.20
8	3 parts SO_2 per million	.43	.18
9	4 parts SO_2 per million	.49	.17

SERIES 4.

["Invisible-injury" experiments—78 10-minute fumigations.]

Check		0.18	.....
4	1 part SO_2 per million	.26	.....
5	2 parts SO_2 per million	.34	.....

In order to determine whether this sulphur was present as sulphides, sulphites, sulph-aldehydes, or fixed sulphates, tests were made as follows:

Samples of the vegetation from plats that had received strong fumigations; that is, No. 17 and 18 and a check plat, were dried to constant weight at 90° C., and 5 to 10 grams was cut into fine pieces with shears and introduced into a 1,500-c. c. round-bottom glass flask. To the flask were added 500 c. c. of distilled water and 10 c. c. of phosphoric acid, and then about 5 grams of sodium carbonate to furnish an atmosphere of cabon dioxide to displace the air.

The flask was connected immediately with a 250-c. c. absorption flask containing about 50 c. c. N/10 iodine solution. An outlet trap from this absorption flask contained about 10 c. c. of iodine solution.

As soon as the connections were made a flame was put under the distillation flask and the contents were brought to a boil, and boiling was continued until about 200 c. c. had collected in the absorption flask. The glass connections were then washed out into a beaker with the contents of the absorption flask.

To insure complete oxidation of the distilled sulphur compounds, the solution was treated with bromine water, after which the bromine was boiled off and the solution was made slightly acid with 5 c. c. of HCl, and the $BaSO_4$ precipitated with $BaCl_2$ solution (about 10 c. c. of a 5 per cent $BaCl_2$ solution). The precipitate was allowed to settle about 24 hours and was then filtered through a Gooch crucible, if enough precipitate was present to filter off.

Results of tests to determine form in which sulphur was present in foliage that had been fumigated.

Number of plat from which sample was taken.	Total sulphur content of foliage.	Sulphur present as sulphoaldehyde.
Vallejo.	*Per cent.*	*Per cent.*
Check	0.43	<0.010
17	.75	.014
18	.82	.014

Blank tests on the reagents failed to give a precipitate of $BaSO_4$.

These tests show that no appreciable amount of sulphur was present in the foliage as sulphoaldehyde. All sulphur was present in fixed combinations.

SUMMARY OF RESULTS OF DETERMINATIONS.

SULPHUR CONTENT OF FOLIAGE.

The sulphur content of foliage that was fumigated with sulphur dioxide was in all cases greater than that of the foliage in the corresponding check plats. In Vallejo series 2 and 3 and Davis series 3 and 4 the sulphur content was greater in the foliage that had received the higher concentration.

It is to be noted that considerable difference existed in the sulphur content of the checks' foliage. In Vallejo check samples, the sulphur content of the foliage varied between 0.34 and 0.52 per cent. The Davis check foliage had more nearly the same sulphur content—between 0.15 and 0.22 per cent.

These data confirm the opinion that the determination of the sulphur content of vegetation is not sufficient alone to determine the extent of the damage that the vegetation may have endured by sulphur dioxide, for great differences are found in the sulphur content of normal uninjured vegetation. In this connection it is interesting to note the conclusions of Tatlock and Thomson.[a]

The claim has been made to the writer that whenever crops of hay have been subjected to sulphur dioxide fumigation and bleached, the sulphur content is increased to the extent that the crops are injurious to animals feeding thereon. If such a condition does exist, it certainly is not due to the increase of sulphur content, for there are differences in the sulphur content of normal unfumigated foliage as great as between bleached and normal foliage.

The foliage from the plats fumigated with heavy sulphur trioxide fume had no greater sulphur content than did the check. This indicates that no sulphur trioxide vapor was absorbed and that no fume was precipitated.

The sulphur was present as sulphates or in other stable compounds.

SULPHUR CONTENT OF GRAIN KERNELS.

The increase of the sulphur content in fumigated grain over that in check grain, although determinable, is very slight.

GERMINATION TEST OF SEEDS.

To determine the effect of sulphur dioxide fumigations upon the germinating power of the grain, samples from various plats of the Davis and Vallejo fields were sent to the seed laboratory of the United States Bureau of Plant Industry, conducted in collaboration with the Agricultural Experiment Station of the University of California.

These germination tests were six days in duration, and were made on the grain about 60 days after the grain had been threshed.

[a] Tatlock, R. R., and Thomson, R. T., Damage caused to vegetation by sulphurous and sulphuric acids in the atmosphere: Analyst, vol. 39, May, 1914, pp. 203-210.

Results of germination tests of barley samples.

SAMPLES FROM VALLEJO EXPERIMENTS IN WHICH VARIOUS TREATMENTS WERE GIVEN.

Plat No.	Treatment of plats.	Germination.
		Per cent.
Check		100
22	2 1-hour fumigations of 10 parts SO_2	90.5
Check		94
98	Fumigated with 6 parts SO_2 per million for 20 minutes while grain was "in dough".	95.5
100	Fumigated with 6 parts SO_2 per million for 2½ hours while grain was "in dough".	91.5

SAMPLES FROM EXPERIMENTS IN VALLEJO SERIES 2—NINETY 10-MINUTE FUMIGATIONS.

	Parts SO_2 per million.	
Check		98
14	1	99
15	2	98
16	3	96
17	4	95
18	5	89

SAMPLES FROM VALLEJO PLATS TREATED WITH SULPHUR TRIOXIDE FUME FUMIGATIONS.

Check		82.5
89	Fumigated with 0.021 gram of SO_3 per cubic meter for 2½ hours	85.5
Check		94
96	Fumigated with 0.033 gram of SO_3 per cubic meter for 1½ hours	92.5

SAMPLES FROM DAVIS EXPERIMENTS IN WHICH VARIOUS TREATMENTS WERE GIVEN.

Check		93
11	Fumigated with 5 parts of SO_2 per million for 1 hour during early growth	90.5
Check		97
26	Fumigated with 10 parts of SO_2 per million for 1½ hours when grain was "in dough."	94.5

SAMPLES FROM EXPERIMENTS IN DAVIS SERIES 2.

[Fifty-three 10-minute fumigations.]

	Parts SO_2 per million.	
Check		97
1	5	88.5
2	4	91.5
3	3	97

SAMPLES FROM EXPERIMENTS IN DAVIS SERIES 3.

[One hundred and ninety-nine fumigations of 5 minutes each.]

	Parts SO_2 per million.	
Check		97
6	1	95
7	2	97
8	3	98
9	4	96

LABORATORY EXPERIMENTS TO DETERMINE THE RATE OF DISAPPEARANCE OF SULPHUR DIOXIDE FROM DILUTE MIXTURES.

In the fumigation experiments at Vallejo and Davis it was found that if a mixture of sulphur dioxide and air was contained in a closed cabinet over vegetation or soil there resulted a very rapid disappearance of the sulphur dioxide from the mixture. This rapid disappearance was found to take place both in the regular fumigation experiments in the celluloid cabinets and in the special experiments in the glass cases. With the apparatus at hand in the field it was not possible to determine accurately whether this disappearance was due entirely to absorption by the vegetation or was due partly to oxidation to sulphur trioxide. Thus it became necessary to carry out some similar experiments in the laboratory to check the field experiments and to determine the extent of the oxidation of sulphur dioxide to trioxide. These experiments were conducted in the laboratory of the Bureau of Mines at San Francisco by Mr. G. C. Bartells, jr., assisted during part of the time by Mr. G. N. Libby.

This experimental work was divided into two series. In one series data were obtained concerning the rate of disappearance of sulphur dioxide from a mixture in contact with vegetation or soil, confirming the data obtained in the field experiments. In the second series data were obtained concerning the rate of disappearance of sulphur dioxide from a mixture of that gas and air contained in a closed glass container under different conditions as to humidity and sunlight. Some data were obtained in this series to explain the disappearance of the sulphur dioxide—whether due to oxidation to the trioxide or due to "adsorption" on the walls of the glass container.

In the experiments to determine the rate of disappearance of the sulphur dioxide from a mixture in contact with vegetation a 36-liter carboy was used as a container. The bottom of this carboy had been removed to allow setting the carboy down over the plants growing in a box, the soil in the box forming the bottom of the carboy. When tests were made on potted plants or cut foliage the carboy was placed on a glass plate which was ground to make a tight joint with the walls of the carboy.

The method of carrying out the tests and the details of the data obtained are described in the report of Mr. G. C. Bartells, jr. (pp. 308–323).

The laboratory experiments confirmed the data obtained in the field by showing that the disappearance of sulphur dioxide from a mixture of that gas and air held in a closed container in contact with vegetation is very rapid. For example, several tests with an initial concentration of 28 parts SO_2 per million parts of air in the carboy over barley plants showed a disappearance of about 80 per cent of the

sulphur dioxide from the mixture in less than 3 minutes and 95 per cent in 10 minutes. In less than 40 minutes the disappearance was complete.

In contact with the soil alone the disappearance of sulphur dioxide was very rapid, though not so rapid as when growing vegetation was present. In less than 10 minutes over 90 per cent of the sulphur dioxide had disappeared. The disappearance did not go to completion in this case, however, a residue of about 2 per cent of the original concentration, or about 0.0010 gram SO_2 per cubic meter, remaining in the gas phase after several hours.

It was found also that green vegetation, although cut from the vines, shrubs, or trees, absorbed the sulphur dioxide very rapidly. From concentrations of approximately 37 parts SO_2 per million a variety of cut vines and other foliage effected a disappearance of about 40 per cent of sulphur dioxide in 10 minutes. In this case also the disappearance of the sulphur dioxide did not go to completion, a residual concentration of about 0.5 part SO_2 per million parts of air by volume remaining in the carboy for several hours.

In the experiments to determine the rate of disappearance of sulphur dioxide from dilute mixtures of that gas and air held in a glass container it was found that in diffused light and with dry atmosphere the disappearance of the sulphur dioxide was very slow. In 2 hours no determinable amount of sulphur dioxide had disappeared. In 30 hours less than 10 per cent had disappeared. In diffused light and with some moisture present (about 50 per cent of the amount required to saturate the atmosphere of the carboy) the disappearance was more rapid, approximately 20 per cent disappearing in 30 hours. Under the same diffused light, but in an atmosphere saturated with water vapor and with excess water present in the carboy, the disappearance was still more rapid, 50 per cent disappearing from the gas phase in 10 minutes and about 90 per cent disappearing in 20 hours. The amount that disappeared in these two latter cases was greater than could be held in direct solution in the water in equilibrium with the gas concentration. This fact indicates that oxidation was very rapid or that the sulphur dioxide was chemically combined with the alkaline salts from the glass or else that "adsorption" on the walls of the glass took place.

In the direct sunlight the disappearance of the sulphur dioxide was more rapid than in the diffused light. Unfortunately these experiments in the sunlight were not conducted under the same range of humidity conditions as were the experiments in the diffused light. In a comparatively dry atmosphere, during a period of about 45 hours, during 11 of which there was direct sunlight, the total disappearance was 38 per cent as against only 10 per cent in diffused light.

The data concerning the oxidation of sulphur dioxide to the trioxide in dilute mixtures contained in glass vessels indicate that the action is comparatively slow.

When sulphur dioxide was present to the extent of about 30 parts SO_2 per million parts of air by volume (0.091 gram per cubic meter) in a dry carboy for a period of about 60 hours, during 12 hours of which there was direct sunlight, approximately 10 per cent of the sulphur dioxide was oxidized to the trioxide.

In an atmosphere saturated with water vapor and with excess moisture present, in diffused light, the oxidation to the trioxide took place more rapidly, 20 per cent being converted to the trioxide in 20 hours.

The oxidation to the trioxide did not account entirely for the disappearance of the sulphur dioxide in the experiments of series 2. These investigations show that "adsorption" took place, a determinable amount of the sulphur dioxide being found on the walls of the carboy even under conditions of comparative dryness. With excess moisture present, this "adsorption" took place to a greater extent. From a concentration of about 0.091 gram per cubic meter, in 20 hours approximately 50 per cent of the sulphur dioxide originally present in the gas phase was "adsorbed" on the walls of the carboy.

As the oxidation of the sulphur dioxide to the trioxide was found to be a matter of hours rather than minutes, even with moisture present, it follows that the extremely rapid disappearance of the sulphur dioxide from the fumigating mixtures must necessarily be due to absorption by the plants and soil, and not to oxidation of the sulphur dioxide.

LABORATORY EXPERIMENTS TO DETERMINE THE EFFECT OF SULPHUR TRIOXIDE FUME OR SULPHURIC ACID MIST ON VEGETATION UNDER DIFFERENT HUMIDITY CONDITIONS.

In the field experiments at Vallejo, it was found that fumigation of barley plants with fumes from sulphur trioxide for periods of one to three hours produced no visible injury or any bleach similar to that produced by sulphur dioxide. Only when the foliage was wet and there resulted the formation of acid drops on the leaves did any injury whatever take place. In order to supplement this work, some few experiments were conducted in the laboratory to determine approximately the conditions under which injury will or will not be produced by sulphur trioxide.

The apparatus for this work was that used in the experiments to determine the rate of disappearance of sulphur dioxide from dilute mixtures. The fumigations were made in the 36-liter carboy from

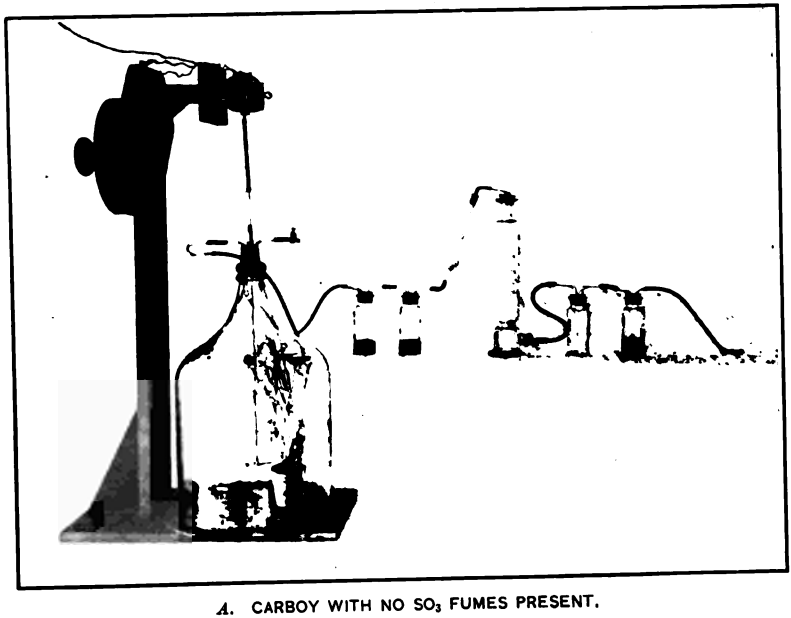
which the bottom had been removed. The barley experimented on was about 30 cm. high, and was transplanted into pots which could be placed on the ground-glass plate that formed the bottom of the carboy.

The sulphur trioxide fumes were produced by aspirating air through fuming sulphuric acid. The air for that purpose was first dried by aspirating it through sulphuric acid and a calcium chloride tower. Thus the fumes from the Nordhausen acid were nearly 100 per cent SO_3 as they were delivered into the carboy. However, from the vegetation and soil in the carboy, there was sufficient exudation of moisture to increase the atmospheric moisture content and thus to increase the moisture content of the fume, causing the formation of acid particles. Thus, in these experiments at no time did we have absolutely dry SO_3 fume or vapor.

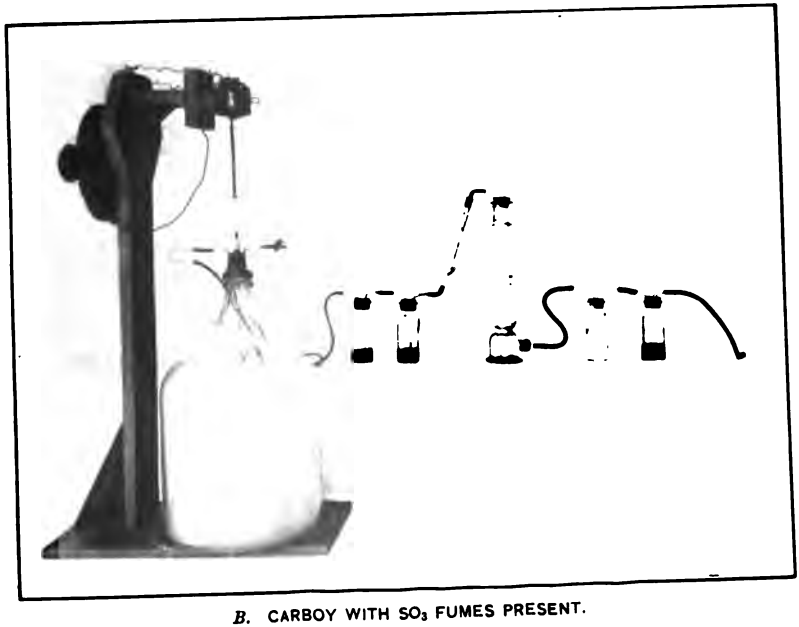
The concentrations of sulphur trioxide used in these fumigations were very high, varying between 2 and 2.5 grams SO_3 per cubic meter (equivalent to the conversion of 600 to 650 parts SO_2 per million parts of air by volume). These concentrations were determined by analyses of samples taken from the carboy. This concentration of fume was so dense that with any moisture present it was impossible to see the stirring fan or the vegetation in the carboy from the outside. Plate XXVI, *A*, shows the carboy with no fumes present. Plate XXVI, *B* shows the carboy with the sulphur trioxide, fumes present.

In these experiments it was found that under comparatively dry conditions—or in other words, when the conditions were the least favorable for the formation of acid particles—fumigations with SO_3 fume produced very little, if any, injury on the foliage of the barley.

In the fumigations that produced the least amount of injury or none at all there was maintained a steady stream of dry air carrying sulphur trioxide fume through the carboy. The suspension of the fume was aided by the revolution of the quartz fan in the carboy. Under these conditions fumigations with concentrated fume (2 grams SO_3 per cubic meter) lasting for three or four hours failed to produce more than very slight injury. Analysis of the air taken from the carboy during these fumigatious showed the presence of some sulphur dioxide (from 2 to 4 parts SO_2 per million), which was undoubtedly due to the presence of sulphur dioxide dissolved in the Nordhausen acid. The slight injury found on the foliage after these fumigations was that produced by this sulphur dioxide. The concentration of sulphur trioxide was equivalent to the conversion of 600 parts SO_2 per million. The bleaching that would have resulted from the application of this concentration of sulphur dioxide for a period of even less than five minutes would have been extremely severe; absolutely



A. CARBOY WITH NO SO_3 FUMES PRESENT.



B. CARBOY WITH SO_3 FUMES PRESENT.

all of the foliage would have been bleached. Yet in four hours' fumigation with this concentration of sulphur trioxide there was produced only very slight injury, which was characteristic of sulphur dioxide, and this was undoubtedly due to the sulphur dioxide in the mixture.

However, when the carboy was filled with the very dense fumes of SO_3, then closed, and the atmosphere in the carboy allowed to remain quiescent, the exudation of the moisture from the vegetation or the soil caused the formation of acid particles. These acid particles settled on the glass walls of the carboy and on the vegetation. In several fumigations the acid fumes or mist were practically settled out in about two hours. In these fumigations there was produced decided injury to the vegetation. The injury that was produced by these fumigations was dissimilar to that produced by sulphur dioxide. In the case of the acid injury there was an actual burning or drying up of the tissue of the foliage in the places where the drops of acid had stood. In some places a hole was eaten through the leaf. This effect of the SO_3 was distinctly corrosion or dessication, and the result did not resemble the bleach produced by sulphur dioxide.

In the case of severe injury produced by sulphur dioxide the bleach was greatest near the tip ends of the leaves or between the veins of the leaves. In the case of the sulphur trioxide or acid injury, however, the injury was confined to the portion where the drops of acid had stood. Thus the injury was found across the veins, and as frequently near the stems of the plants as at the tip end of the leaves.

The results of these few laboratory experiments confirmed the data obtained from the field experiments in showing that the injury that is produced by sulphur trioxide vapor, or dry SO_3 fume, is comparatively slight, if any takes place at all. Only when the sulphur trioxide unites with moisture to form acid particles does any injury result. Injury then can take place only when these acid particles are brought into contact with the leaves and are precipitated there. In this case the injury is confined solely to those spots where the acid particles are precipitated, and the injury is one of corrosion or dessication at those spots, not of bleaching.

DISAPPEARANCE OF SULPHUR DIOXIDE FROM DILUTE MIXTURES OF SULPHUR DIOXIDE WITH AIR.

By G. C. Bartells, jr.

INTRODUCTION.

The following investigations were carried on to confirm and explain, if possible, certain observations made in the field-fumigation experiments conducted by the Selby Smelter Commission. It was observed that when sulphur dioxide was introduced into a cabinet over barley plants a rapid disappearance of sulphur dioxide from the gas phase took place, and it was a question whether this was due to absorption by the plants or oxidation to sulphur trioxide.

This laboratory experimental work was divided into the following series:

1. The determination of the rate of disappearance of sulphur dioxide from a mixture of that gas and air in contact with (*a*) barley growing in black soil; (*b*) black soil alone; (*c*) various forms of green foliage cut from trees, vines, or shrubs.

2. The determination of the rate of disappearance of sulphur dioxide from a mixture of that gas and air held in a glass container (no vegetation or soil present) under various humidity and light conditions.

(*a*) Disappearance in diffused light in a dry atmosphere.

(*b*) Disappearance in diffused light in an atmosphere containing some moisture—about 50 per cent of saturation.

(*c*) Disappearance in diffused light and with slight excess of moisture present.

(*d*) Disappearance in direct sunlight in a dry atmosphere.

(*e*) The determination of the relative amounts of sulphur dioxide oxidized to the trioxide and that adsorbed on the walls of the glass container.

The first experiments to be considered are those of series 1, in which the disappearance of sulphur dioxide over various forms of vegetation was studied.

For these tests a 36-liter carboy (Pl. XXVII, *A*) from which the bottom had been removed was used as a hood. In the neck of the carboy was cemented a glass stopper, through which three holes

A. THIRTY-SIX-LITER CARBOY WITH BOTTOM REMOVED.

B. CARBOY HOOD WITH INLET TUBE CONNECTED.

C. PLANT SAMPLE IN CARBOY HOOD.

were drilled and glass tubes inserted. A tube extending just through the neck of the carboy was for the inlet of the air when samples were withdrawn. Another extending to about the center of the carboy was used for introducing the gas mixture and for withdrawing the samples for analysis. The third tube was for the purpose of holding the shaft of the fan by which the gas mixture was kept in circulation. This fan was made of quartz, and the top of the shaft was sealed with mercury to eliminate leakage. The fan was propelled by a small motor held above the carboy.

It is obvious that any change in the concentration of the gas inside the carboy was not due to any appreciable leakage.

In this group of experiments the carboy was set over the sample being treated. In the case of growing grain the soil and grain formed the bottom. If leaves of trees or leaves of grain were used, a glass that had been ground to fit the carboy was used to form the bottom.

METHOD OF INTRODUCING GAS MIXTURE.

A known concentration of sulphur dioxide gas was prepared by successively diluting the pure gas with air in a gas burette over mercury. A measured volume of this mixture was then introduced into the carboy through the long inlet tube (Pl. XXVII, *B*). The fan was then started to mix this volume with the air of the carboy.

In all cases the glass tip of the burette was butted against the glass entry tube of the carboy, so that the sulphur dioxide mixture would not be affected by the action of the rubber tubing. The outlet tube was left open, so that atmospheric pressure was maintained in the carboy while the mixture was being introduced.

METHOD OF SAMPLING GAS MIXTURE.

Two 2-liter acid bottles were fitted with test tubes of 50-c. c. capacity by means of rubber stoppers and glass tubing (Pl. XXVIII, *A*). One bottle was used as a "check," the other for withdrawing the sample.

This latter bottle, the "sample" bottle, for each test was evacuated by means of a pump to about one-half an atmosphere, thereby giving a sampling capacity of 1 liter.

Before the bottle was evacuated about 25 c. c. of weak iodine solution, to which a little starch indicator had been added, was shaken around in each bottle. The colors of these solutions were then compared, and if not identical, the solutions were brought to the same color and returned to their respective bottles. This operation was repeated until the solutions, after shaking, were identical in color. It is essential that a very pale blue color be used in the "check" to

titrate back to, or else small differences of color can not be determined accurately.

The evacuated sampling bottle was then connected with the carboy outlet tube, care being taken to butt the glass connections as close as possible. When the pressures in the carboy and sample bottle had equalized, the sample-bottle tube was closed with a screw clamp. The iodine solution was then run down into the bottle, and this bottle, as well as the "check," was vigorously shaken to insure complete contact of gas and iodine solution. If the solution was decolorized, sufficient iodine solution was added to bring it back to the color in the "check" bottle.

IODINE SOLUTIONS.

The iodine solutions were made up (approximately 0.0003 normal) in small quantities. They were frequently standardized against 0.001 normal arsenic trioxide, for they readily dissipate on standing, even in a dark place.

It was found that when 50 c. c. of starch solution was used in the bottles it was possible to detect a change in color brought about by the addition of 0.1 c. c. of this weak iodine solution. One-tenth of a cubic centimeter of this solution was equivalent to about 0.0003 c. c. of sulphur dioxide, which was equivalent, in a liter sample, to 0.3 part of sulphur dioxide per million parts by volume.

The strength of the sulphur dioxide mixtures was kept in the limits, 1 to 30 parts per million by volume, so as to be somewhat comparable to the strength of the mixtures used in the field work.

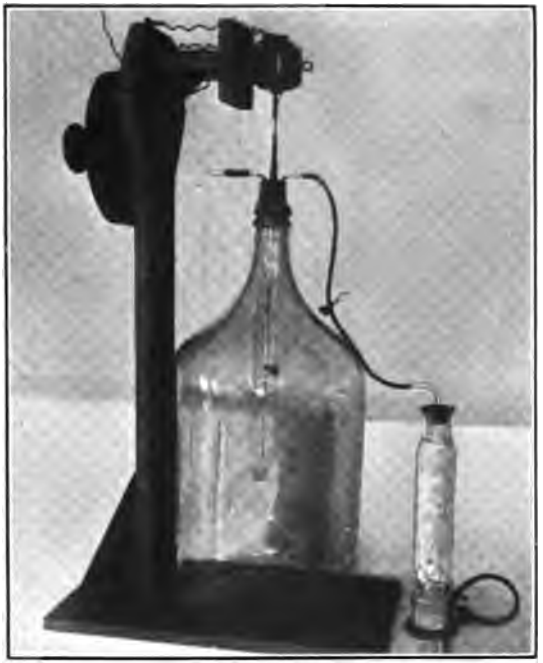
EXPERIMENTS IN SERIES 1.

TESTS WITH BARLEY PLANTS.

In Table 1 are given the results of a series of tests made with a stand of barley, which was 30 cm. high and about ready to head out. The barley had been replanted into a wooden box in good soil. Although it was not growing very vigorously, on account of the transplanting, yet it was green throughout.

From these results it is seen that about 75 to 80 per cent of the sulphur dioxide in a mixture of 28 parts SO_2 per million disappeared within about 2 minutes, and that in about 35 to 40 minutes the disappearance was practically complete. Considerable moisture was present, both in the soil and in the leaves, which no doubt aided materially in the disappearance of the sulphur dioxide.

A. APPARATUS FOR SAMPLING GAS MIXTURE FROM CARBOY.



B. THIRTY-SIX-LITER GLASS CARBOY USED IN FUMIGATION EXPERIMENTS.

TABLE 1.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in contact with barley growing in black soil.*

[1 c. c. iodine solution equivalent to 0.0037 c. c. SO_2; 20 c. c. of 5 per cent SO_2 mixture introduced.]

Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of the atmosphere.
	36-liter carboy.	1-liter sample.					
		Theoretical.	Actual.				
Minutes.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*	*Per cent.*
0	272.0	7.6	.....	28.1	.....		
4	264.4	7.4	1.0	3.7	87		
6	257.0	7.2	.4	1.4	95	17	60
10	249.8	6.9	.2	.7	97		
15	242.9	6.7	.1	.4	99		
20	236.4	6.5	.0	.0	100		
0	272.0	7.6	.....	28.1	.....		
2	.....	7.4	1.8	6.7	76		
8	.....	7.2	1.0	3.7	86		
13	.....	6.9	.5	1.8	93	17	60
17	.....	6.7	.4	1.4	94		
21	.....	6.5	.2	.7	97		
26	.....	6.3	.1	.4	99		
0	272.0	7.6	.....	28.1	.....		
3	.....	7.4	1.8	6.7	76		
9	.....	7.2	.7	2.6	90	17	60
14	.....	6.9	.5	1.8	93		
18	.....	6.7	.2	.7	97		
22	.....	6.5	.1	.4	99		
0	272.0	7.6	.....	28.1	.....		
2	.....	7.4	1.7	6.3	77		
9	.....	7.2	.5	1.9	92	17	60
15	.....	6.9	.2	.7	97		
22	.....	6.7	.1	.4	99		
35	.....	6.5	.0	.0	100		
0	272.0	7.6	.....	28.1	.....		
2	.....	7.4	1.6	6.2	77		60
13	.....	7.2	.5	1.9	93	17	
30	.....	6.9	.2	.7	97		
40	.....	6.7	.1	.4	99		
45	.....	6.5	.0	.0	100		
0	272.0	7.6	.....	28.1	.....		
2	.....	7.4	1.4	5.2	81		
8	.....	7.2	.6	2.2	92		
13	.....	6.9	.3	1.1	96	17	60
17	.....	6.7	.2	.7	97		
27	.....	6.5	.1	.4	99		
38	.....	6.3	.0	.0	100		

TESTS WITH SOIL ALONE.

The next test was made with the soil in which the barley had grown, the barley plants simply being removed from the soil in the box. Therefore, the soil was the same in moisture as when the barley and soil were used together for a test.

The results of this test are given in Table 2, and show that the disappearance of the sulphur dioxide was not so rapid, nor does it completely disappear as with the barley plants and soil together. Within about two minutes approximately 60 per cent had disappeared, but even after two hours had passed there was still a residue of sulphur dioxide, indicating a condition of equilibrium between the lphur dioxide content of the soil and that of the carboy atmosphere.

TABLE 2.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in contact with soil alone.*

[1 c. c. iodine solution equivalent to 0.0037 c. c. SO_2; 15 c. c. of 5 per cent SO_2 mixture introduced.]

Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of the atmosphere.
	36-liter carboy.	1-liter sample.					
		Theoretical.	Actual.				
Minutes.	*C c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*	*Per cent.*
0	203.0	5.6	.....	20.8	.....		
2	197.4	5.5	2.2	8.1	60		
8	191.9	5.3	.6	2.2	89		
13	185.6	5.2	.4	1.4	92		
20	180.4	5.0	.3	1.1	94		
27	175.4	4.8	.2	.7	96	16	89
68	170.6	4.7	.1	.4	98		
110	165.9	4.6	.1	.4	98		
138	161.3	4.5	.1	.4	98		
157	156.8	4.3	.1	.4	98		
0	203.0	5.6	.....	20.8	.....		
2	.....	5.5	2.5	9.3	55		
7	.....	5.3	.8	2.9	89		
13	.....	5.2	.4	1.4	92		
19	.....	5.0	.4	1.4	92	16	89
31	.....	4.8	.3	1.1	94		
60	.....	4.7	.3	1.1	94		
113	.....	4.6	.1	.4	98		
140	.....	4.5	.1	.4	98		

TESTS WITH MISCELLANEOUS FOLIAGE, NOT GROWING.

A series of tests was next made with vegetation of various kinds, the results of which are given in the table following.

These samples of vegetation were obtained from the university campus and were treated the same day they were obtained, so that they were all green and vigorous. They were supported inside of the carboy on a glass stand, so that all parts of the sample were exposed to the action of the sulphur dioxide mixture (see Plate XXVII, *C*).

No appreciable damage resulting from the sulphur dioxide treatment was observed on any samples except the grapevine, and this was quite noticeable the following day especially, showing in a bleached condition of the whole leaf, accompanied by a decided wilting.

It is to be noted that in none of these tests was the disappearance of sulphur dioxide carried to completion, as in the test of the soil and barley combined, a small residue of the sulphur dioxide remaining in the air of the carboy.

TABLE 3.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in contact with various vegetable growths.*

[1 c. c. iodine equivalent to 0.0032 c. c. SO_2; 27 c. c. of 5 per cent SO_2 mixture introduced.]

ARBOR VITÆ BRANCHES (WEIGHT, 75 GRAMS).

Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of the atmosphere.
	35-liter carboy.	1-liter sample.					
		Theoretical.	Actual.				
Minutes.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*	*Per cent.*
0	425.0	.....	.....	37.5	.....		
3	413.2	11.4	7.1	22.4	38		
10	401.8	11.2	5.7	18.2	49		
13	390.6	10.8	5.4	17.2	50		
20	379.8	10.5	3.6	11.5	65		
25	369.3	10.3	3.1	9.9	70	17	72
45	359.0	10.0	2.0	6.4	80		
50	349.0	9.7	1.7	5.4	83		
70	339.3	9.4	1.1	3.5	88		
75	329.9	9.2	.7	2.2	92		
135	320.7	8.9	.4	1.3	96		
140	311.8	8.7	.2	.7	98		

GRAPEVINE LEAVES AND STALK (WEIGHT, 55 GRAMS).

0	425.0	.....	.....	37.5	.....		
3	.....	11.4	6.5	20.8	43		
8	.....	11.2	2.2	7.1	80		
15	.....	10.6	1.2	3.9	89		
20	.....	10.5	.6	1.9	94	19	65
25	.....	10.3	.4	1.3	96		
45	.....	10.0	.3	1.0	97		
60	.....	9.7	.1	.3	99		
110	.....	9.4	.1	.3	99		

PEACH LIMB AND LEAVES WITH FRUIT (WEIGHT, 165 GRAMS).

0	425.0	11.8	.....	37.5	.....		
5	.....	11.5	5.8	18.5	50		
12	.....	11.2	2.1	6.7	81		
20	.....	10.9	1.4	4.5	87		
25	.....	10.5	.7	2.2	93		
30	.....	10.2	.6	1.9	94	19	65
35	.....	10.0	.5	1.6	95		
55	.....	9.7	.4	1.3	96		
130	.....	9.4	.3	1.0	97		
145	.....	9.2	.3	1.0	97		
165	.....	8.9	.2	.6	98		
180	.....	8.7	.2	.6	98		

APPLE LIMB AND LEAVES WITH SMALL FRUIT (WEIGHT, 100 GRAMS).

0	425.0	11.8	.....	37.5	.....		
5	.....	11.5	7.0	22.0	39		
10	.....	11.2	4.7	15.0	58		
15	.....	10.9	4.0	12.8	63		
20	.....	10.5	3.3	10.5	68		
30	.....	10.2	1.4	4.5	86	19	65
40	.....	10.0	.8	2.6	92		
60	.....	9.7	.4	1.3	96		
65	.....	9.4	.4	1.3	96		
80	.....	9.2	.2	.6	98		
95	.....	8.9	.2	.6	98		

EXPERIMENTS IN SERIES 2.

All of the following tests were carried out in a 46-liter glass carboy, with the bottom left in, so that there was a complete glass surface exposed to the action of the gas mixtures (Pl. XXVIII, *B*). The neck was stoppered with glass, and the inlets and outlets were similar to those in the carboy described above.

The method used for drying out this carboy was as follows: It was thoroughly washed out with distilled water and drained, set upside down on a tripod, and, through a two-hole stopper in the neck, dry air was blown through the carboy for about three hours.

This air was dried by passing compressed air through potassium permanganate, calcium chloride, and sulphuric acid towers in series. Just before passing into the carboy, the air was heated to accelerate the evaporation of the moisture present in the carboy. As an additional means of drying, air dried by calcium chloride was drawn through in sufficient quantity to displace all of the air in the carboy.

The method of introducing the sulphur dioxide mixture was the same as described for previous experiments. The method of withdrawing the sample was the same, with this addition, that the air that was drawn in to replace the sample was drawn through a calcium chloride tower to maintain the dry condition where such was desired.

The first test carried on was to determine the action of the sulphur dioxide mixture under the dry conditions, brought about as described above, in the diffused light of a laboratory.

The figures in Table 4, giving the results of the tests, show that after a considerable period there was a slight disappearance of sulphur dioxide. No data are available for the interval between 4½ hours and 20 hours, so that the disappearance may be more gradual than is indicated in the table.

TABLE 4.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a dry carboy in diffused light.*

[1 c. c. iodine solution equivalent to 0.0031 c. c. SO_2.]

17 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.
	46-liter carboy.	1-liter sample.				
		Theoretical.	Actual.			
H. m.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*
0	272.0	6.0	6.0	22	.....	
5	266.0	5.8	5.8	.....	0	
20	260.2	5.7	5.7	.....	0	
40	254.5	5.5	5.5	.....	0	
1 0	249.0	5.4	5.4	21	0	16
2 15	243.6	5.3	5.3	20	0	
45	238.3	5.2	5.2	.....	0	
3 40	233.1	5.1	5.1	19	0	
4 25	228.0	5.0	5.0	18	0	
22 0	223.0	4.8	4.4	16	8.3	
40	218.2	4.7	4.3	.....	8.5	
23 25	213.5	4.6	4.2	.....	8.7	
24 0	208.9	4.5	4.1	15	11.0	15
28 30	204.4	4.4	4.0	.....	9.1	
29 30	200.0	4.3	3.8	14	11.5	

30 C. C. OF 6 PER CENT SO_2 INTRODUCED.

0	580.0	12.6	12.6	39	.....	
10	567.4	12.3	12.2	.....	.....	
15	555.1	12.0	12.0	.....	.....	
25	543.0	11.8	11.8	.....	.....	
30	531.2	11.5	11.6	.....	.....	16
1 0	520.7	11.3	11.3	35	.....	
20	509.4	11.0	11.0	.....	.....	
40	498.4	10.8	10.7	.....	.....	
20 0	487.6	10.6	9.7	30	8.5	.....
5	477.0	10.3	9.5	.....	7.8	.....
15	465.7	10.1	9.2	.....	8.9	.....
40	455.6	9.9	9.0	28	9.1	.....

The following test was carried on in the carboy in an atmosphere 50 per cent saturated with water vapor, the carboy standing in diffused light. The distinctive feature of this following test was the addition of sufficient water to produce 50 per cent saturation at the temperature obtaining in the carboy.

As the disappearance of the sulphur dioxide progressed, its concentration in the carboy was thereby lowered, so that an additional amount of sulphur dioxide mixture had to be added to bring the gas to a suitable strength, as is shown in Table 5 following. This test was carried on at intervals extending over a week end, and some of the intermediate figures are wanting, but the action of the sulphur dioxide mixture under these conditions is clearly indicated from the figures given.

It is to be noted that when a sample for analysis was withdrawn, the air drawn in to replace it was taken direct from the outside air, so that the humidity in the carboy was slightly increased, for at all times

the humidity of the outside air was above 50 per cent. A fuller discussion of this is made in the conclusions.

From the data given it is evident that the rate of disappearance under these conditions of semisaturation is much greater than under dry conditions. The figures for the percentage of disappearance are higher in the first test (48 hours), but it is to be noted that the humidity of the air during this test was high, so that the air drawn in, carrying in all about 0.25 gram of moisture, raised the humidity to about 75 per cent inside the carboy toward the last part of the test.

TABLE 5.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy, the air being 50 per cent saturated with moisture.*

14.6 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

[1 c. c. of iodine solution equivalent to 0.0037 c. c. of SO_2.]

Test.	Time elapsed.	Quantity of iodine solution required for— 46-liter carboy.	1-liter sample. Theoretical.	1-liter sample. Actual.	Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of atmosphere.
	H. m.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*° C.*	*Per cent.*
A	0 0	200.0	4.4	.....	16	0.0		
	5	195.6	4.3	4.2	.....	2.3		
	20	191.4	4.2	4.0	.....	4.2		
	2 0	187.3	4.1	3.7	14	9.7		
	3 30	183.3	4.0	3.6	.....	10.0	18	98
	50	179.3	3.9	3.5	.....	10.1		
	4 40	175.4	3.8	3.4	13	10.5		
	22 0	171.6	3.7	3.2	12	13.5		
	20	167.9	3.6	3.1	.....	14.0		
20 C. C. OF 5 PER CENT SO_2 MIXTURE WAS ADDED AT THIS TIME.								
	22 25	[a] 272.0	9.6	8.2	[b] 31	14.6		
	35	426.7	9.3	8.0	.....	14.0		
	45	417.4	9.1	7.8	.....	14.3		
	47 0	408.3	8.9	6.2	23	30.5		
	15	399.4	8.7	6.1	.....	29.5	18	98
	25	390.7	8.5	5.7	.....	30.0		
	30	382.2	8.3	5.7	.....	31.5		
	48 0	373.9	8.1	5.6	20	31.0		
30 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED. [1 c. c. iodine solution equivalent to 0.00374 c. c. SO_2.]								
B	0 0	396.0	8.7	8.7	33	0.0		
	5	387.3	8.4	8.4	.....	.0		
	30	378.9	8.2	8.1	.....	1.2		
	35	370.7	8.0	7.8	.....	2.5		
	2 25	362.7	7.9	7.4	28	6.3		
	30	354.8	7.7	7.1	.....	7.8		
	3 0	347.1	7.5	6.9	26	8.0	16	70
	35	339.6	7.4	6.9	.....	6.8		
	40	332.2	7.3	6.7	.....	8.2		
	4 30	324.9	7.0	6.4	24	8.6		
	40	317.9	6.9	6.3	.....	8.7		
	50	311.0	6.8	6.1	.....	10.1		
	22 0	304.2	6.7	5.8	22	13.4		
	23 45	294.4	6.4	5.3	20	17.2		
	24 5	281.7	6.2	5.1	19	17.5	17	60
	25 30	275.5	6.0	5.0	.....	16.8		
	46 20	263.6	5.8	4.4	16	24.0	19	80

[a] Actual quantity added; theoretical quantity needed, 164.3 c. c. [b] Actual; theoretical, 36 parts.

The following tests were carried on with the air in the carboy fully saturated, this being accomplished by introducing about 20 c. c. of water, which was well shaken to thoroughly distribute the moisture about the carboy.

All of these tests were carried on over a period of about 20 hours, and it is to be noted that the first 50 per cent of sulphur dioxide disappeared very rapidly in about the first hour. Also, that the rate of disappearance of the following 40 per cent was much greater than in the test in which the air in the carboy was in a semisaturated condition.

The amount of water introduced into the carboy was in excess of the amount needed to saturate the air in the carboy, the calculated amount being about 1 c. c. This excess of water in the carboy, without doubt, had a solvent action on the sulphur dioxide in the gas mixture, which, to some small degree, accounts for the initial rapid disappearance of the sulphur dioxide. However, the solubility of sulphur dioxide from dilute mixtures is very low, so that as a direct solvent of the gas the water would act to only a small degree.

TABLE 6.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy, the air being 100 per cent saturated with moisture.*

25 C. C. OF 5 PER CENT SO_2 MIXTURE ADDED.

[1 c. c. iodine solution equivalent to 0.0037 c. c. SO_2.]

Test.	Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of atmosphere.
		46-liter carboy.	1-liter sample.					
			Theoretical.	Actual.				
	H. m.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*° C.*	*Per cent.*
A	0 0	335.0	7.3	.....	27	.....		
	3	335.0	7.3	3.9	14	47		
	5	327.7	7.1	3.3	.....	53		
	15	320.6	6.9	2.9	.....	58		
	22	313.7	6.8	2.6	.....	62		
	40	306.9	6.7	2.3	.....	66	18	98
	1 0	300.2	6.5	2.3	9	65		
	2 0	293.7	6.4	2.0	7	69		
	10	287.3	6.3	1.9	.....	70		
	19 0	281.0	6.1	1.0	4	84		
	20 0	263.0	5.7	.6	2	90	[a]17	94

[a] 20 c. c. of water was introduced into the carboy and shaken around well to give it a saturated atmosphere at this temperature.

TABLE 6.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy, the air being 100 per cent saturated with moisture*—Contd.

30 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

[1 c. c. iodine equivalent to 0.0031 c. c. SO_2.]

Test.	Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.	Relative humidity of atmosphere.
		46-liter carboy.	1-liter sample.					
			Theoretical.	Actual.				
	H. m.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*° C.*	*Per cent.*
B	0 0	484.0	10.5	.....	32	.....		
	5	484.0	10.5	6.5	.....	38		
	10	473.5	10.3	6.3	.....	39		
	15	463.2	10.1	6.0	.....	40		
	20	453.1	9.8	5.8	.....	41		
	30	443.3	9.6	5.5	.....	43	17	88
	45	433.6	9.4	5.0	.....	47		
	1 5	423.2	9.2	4.2	13	55		
	20	414.0	9.0	4.0	.....	56		
	2 0	405.0	8.8	3.5	11	60		
	10	396.2	8.6	3.4	.....	60		
	19 0	387.6	8.4	.8	3	90		
	20 0	363.0	7.8	.4	1	95	[a] 17	82
C	0 0	484.0	10.5	.....	27	.....		
	5	484.0	10.5	7.2	.....	33		
	10	473.5	10.3	6.6	.....	36		
	15	463.2	10.1	5.0	.....	50		
	20	453.1	9.8	5.0	.....	49		
	30	443.3	9.6	4.6	.....	52		
	40	433.6	9.4	4.4	.....	53	[a] 18	65
	1 0	423.2	9.2	4.0	12	56		
	50	414.0	9.0	3.5	.....	61		
	2 0	405.0	8.8	2.5	8	72		
	15	396.2	8.6	2.2	.....	72		
	19 15	379.2	8.2	1.0	.....	87		
	20 0	363.0	7.9	.9	3	89		

[a] 20 c. c. of water was introduced into the carboy and shaken around well to give it a saturated atmosphere at this temperature.

The last series of tests was made with the carboy standing in the direct sunlight on a platform outside of the laboratory.

The carboy was dried out as previously described, and all the air drawn in when samples were withdrawn was drawn through calcium chloride to preserve the dry condition in the carboy. The table (Table 7) shows that each of these tests extended over a certain number of hours, the hours being continuous from the time the test was started. It is to be noted, however, that the actual number of hours of direct sunlight is much less than the total number of hours given in the table. The number of hours of total direct sunlight are given for each test in a note below each test. The prolonged action of the direct sunlight on the sulphur dioxide mixture does not cause the disappearance of the sulphur dioxide to increase very much after a certain point has been reached. For instance, the additional sunlight in test B, an excess of nine hours over test A, has not increased the percentage disappearance to any appreciable extent.

TABLE 7.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy standing in direct sunlight.*

30 C. C. OF 6 PER CENT SO_2 MIXTURE ADDED.

[Atmosphere in the carboy considered dry; 1 c. c. iodine solution equivalent to 0.0030 c. c. SO_2.]

Test.	Time elapsed.	Quantity of iodine solution required for— 46-liter carboy.	1-liter sample. Theoretical.	1-liter sample. Actual.	Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.
	H. m.	*C. c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*
A[a]	0	615.0	13.5	.....	42	.....	.....
	5	615.0	13.5	13.3	.....	1	26
	15	601.5	13.4	13.2	.....	1	27
	30	588.1	13.3	13.1	.....	2	28
	1 5	574.8	12.6	12.3	38	2	31
	15	562.2	12.4	12.0	.....	3	31
	25	549.8	12.3	11.7	.....	5	32
	45	537.5	12.2	10.8	.....	12	36
	2 0	525.4	12.1	10.5	33	12	37
	5	513.3	12.0	10.4	.....	13	38
	30	501.3	11.7	10.2	.....	13	39
	3 0	489.6	11.4	9.5	.....	18	38
	20	478.2	11.2	9.2	.....	18	38
	40	467.0	10.9	9.1	.....	18	37
	4 5	456.1	10.5	8.8	29	16	36
	4 20	445.6	10.2	8.5	.....	17	35
	20 45	435.4	9.6	8.0	25	17	18
	24 0	371.7	8.3	6.2	19	25	29
	26 0	324.7	7.2	4.9	15	32	27
	44 15	296.9	6.5	4.1	13	37	17
	45 0	284.1	6.2	4.0	12	35	18

30 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

[Atmosphere in carboy considered dry; 1 c. c. iodine solution equivalent to 0.00381 c. c. SO_2.]

B[b]	0	386.0	8.4	8.4	32	0	18
	5	377.6	8.2	8.2	.....	0	18
	10	369.4	8.0	7.9	.....	1	18
	40	361.4	8.0	7.6	.....	5	27
	50	353.4	7.9	7.4	.....	6	27
	1 0	345.5	7.7	7.2	27	6	27
	10	337.8	7.6	7.1	.....	7	27
	20	330.2	7.4	7.0	.....	6	27
	30	322.8	7.2	6.8	.....	6	27
	40	315.6	7.0	6.6	.....	6	27
	2 40	308.0	6.9	6.4	24	7	30
	45	301.0	6.7	6.1	.....	9	30
	50	294.4	6.6	6.0	.....	9	30
	25 10	287.8	6.4	5.2	20	19	32
	28 0	251.1	5.7	4.6	17	19	36
(c)	47 20	276.0	6.0	4.1	14	31	29
	97 20	258.3	5.7	3.7	12	35	29
	100 0	221.3	4.8	3.0	10	38	29

30 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

[Atmosphere in carboy considered dry; 1 c. c. iodine solution equivalent to 0.00308 c. c. SO_2.]

C[d]	0	480.0	.....	.....	.....	.....	.....
	5	480.0	10.4	10.5	32	0	19
	10	469.6	10.3	10.2	.....	1	21
	25	459.3	10.1	9.6	.....	5	25
	30	449.2	10.0	9.4	.....	6	26
	35	439.0	9.5	8.5	.....	6	27
	45	429.5	9.3	8.6	.....	7	27
	55	420.2	9.1	8.6	.....	6	28
	1 5	411.1	8.9	8.4	26	6	28
	22 20	402.2	8.4	6.6	20	21	20
	24 5	354.3	7.3	5.8	18	20	28
	25 0	330.0	6.8	5.4	16	21	27

[a] Total of eleven hours of direct sunlight.
[b] Total of 20 hours of direct sunlight.
[c] New iodine solution used here—1 c. c. equivalent to 0.0033 c. c. SO_2.
[d] Total of 4 hours of direct sunlight.

TABLE 7.—*Results of experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy standing in direct sunlight*—Continued.

28 C. C. OF 5 PER CENT SO_2 MIXTURE INTRODUCED.

[Atmosphere in carboy considered dry; 1 c. c. iodine solution equivalent to 0.0037 c. c. SO_2.]

Test.	Time elapsed.	Quantity of iodine solution required for—			Parts of SO_2 per million.	Proportion of SO_2 lost.	Carboy temperature.
		46-liter carboy.	1-liter sample.				
			Theoretical.	Actual.			
	H. m.	*°C. c.*	*C. c.*	*C. c.*		*Per cent.*	*°C.*
D [a]	0	378.5	8.2	.....	31	.....	.....
	5	378.5	8.2	8.1	.....	1.1	20
	10	370.3	8.1	8.0	.....	1.1	21
	15	362.2	7.9	7.8	.....	1.2	23
	30	354.3	7.8	7.4	.....	5.1	28
	40	346.4	7.7	7.1	.....	7.8	28
	45	338.6	7.6	7.1	.....	6.6	29
	1 20	330.9	7.5	6.8	25	9.3	31
	35	323.4	7.3	6.7	.....	8.3	31
	2 0	316.1	7.1	6.5	24	8.5	31
	20	309.0	7.0	6.4	.....	8.6	30
	35	302.0	6.8	6.2	.....	8.8	30
	20 0	295.2	6.4	5.8	21	9.4	18

[a] Total of 2 hours of direct sunlight.

The disappearance of the sulphur dioxide from the gas mixtures in the glass carboy was doubtless due for the greater part to oxidation and adsorption on the walls of the glass carboy.

A strong adsorptive property is characteristic of glass surfaces, and the degree to which adsorption is carried varies with the amount of moisture in the air in contact with the glass surface. In these tests the adsorption takes place on a glass in which there is more or less available alkali present, which, with the moisture, would form an alkaline solution. This has the property of fixing the sulphur dioxide. The greater the amount of moisture present, the greater the amount of sulphur dioxide adsorbed, and the greater the rate of its adsorption. It is evident that some such action as this takes place, from the fact that the amount of moisture present in most of these tests is not sufficient to account for a simple solution of the sulphur dioxide.

The following table presents some of the data obtained in the two groups of experiments, first, in a dry atmosphere in the direct sunlight, and second, in a moisture-saturated atmosphere in diffused light.

I wish to state that these data have not been checked sufficiently to be final, and should be taken only as indicating the possible action that takes place.

Data obtained in experiments to determine rate of disappearance of SO_2 from a mixture of SO_2 and air in a carboy under differing conditions.

AIR IN CARBOY CONSIDERED DRY.

Sulphur introduced as SO_2.	Sulphur in washings as $BaSO_4$.	Sulphur withdrawn for analysis, calculated (1—2).	Sulphur withdrawn for analysis.	Sulphur washed out and titrated against iodine.	Sulphur as residual SO_2 in carboy.	Sulphur absorbed, calculated (5—6).	Sulphur washed out as SO_2, calculated (2—5).
1	2	3	4	5	6	7	8
0.00263.....	0.00120	0.00143	0.00124	0.00093	0.00079	0.00014	0.00027
.00214.....	.00146	.00068	.00060	.00129	.00110	.00019	.00017
.00205.....	.00165	.00040	.00038	.00135	.00132	.00003	.00030

AIR IN CARBOY SATURATED AND IN DIFFUSED LIGHT.

0.00178.....	0.00120	0.00058	0.00013	0.00090	0.00015	0.00085	0.00030
.00215.....	.00165	.00050	.00024	.00130	.00010	.00130	.00035
.00215.....	.00169	.00046	.00023	.00104	.00018	.00086	.00065

The values in column 3 are calculated simply as the difference between the total sulphur introduced as sulphur dioxide and the total sulphur weighed as barium sulphate from the washings. Those in column 4 are obtained by actual titration, and it is to be noted that they are lower. This discrepancy can be explained by considering the values of sulphur from barium sulphate as low, which might occur if the solution in which it was precipitated was strongly acid, and by taking into account also the expansion of the air inside the carboy in the first set of tests, in which the action of direct sunlight was studied. As a matter of fact, as shown in the tables, the increase in temperature inside the carboy ranged from 20° to 35°, which would increase the volume of the gas mixture about 5 per cent, or about 5 per cent of the sulphur dioxide in the mixture was lost, thereby giving low values for column 4. However, for these same values in the tests following in a saturated atmosphere, this expansion loss does not apply. If we consider, however, that the sulphur dioxide in the moist atmosphere was oxidized into sulphur trioxide to a greater degree than in the dry atmosphere, as is indicated by the data in column 8, and that in this condition as a fume or a gas it is withdrawn with the samples and lost, then we can account for a very small part of the discrepancy shown (for it would result in low total sulphur), but the best explanation is that already given, of low barium sulphate weights.

The difference between columns 5 and 6 is indicated as due to adsorption of part of the sulphur dioxide, which is fixed on the surface of the glass by means of the alkali, as noted before.

It is to be noted that in the first set of results in the dry carboy the percentages of the amount of sulphur dioxide adsorbed with respect to the amount introduced do not agree with each other. This is explained by the fact that the amount of adsorption varies with the amount of moisture present, and these carboys supposedly dried by the same method actually contained varying amounts of moisture, as is indicated by this apparent discrepancy.

The percentage of adsorption varies in the tests in the dry carboy from 1.5 to 8.7, while in the tests in the moisture-saturated carboy they agree more closely, averaging about 47 per cent.

The values for the sulphur as sulphur trioxide are to be taken as relative results rather than as actual, for the reason that there is the possibility of the barium sulphate determinations being low, and it is from these that the sulphur trioxide values are calculated.

That the actual oxidation of sulphur dioxide into sulphur trioxide takes place more rapidly in moist conditions than in dry is evidenced by the somewhat higher results in column 8, the values in the dry condition averaging about 11 per cent, while those in the moist averaged about 21 per cent of the total introduced as sulphur dioxide into the carboy.

I would like to say in conclusion that these experiments were started primarily with the idea of ascertaining the amount of disappearance, and also the rate of disappearance, and that the data giving the cause for the disappearance are not comprehensive enough to be final.

SUMMARY.

From the data obtained in these tests it is evident:

(*a*) That when a mixture of sulphur dioxide and air was introduced into a closed glass carboy and brought into contact with green vegetation, the sulphur dioxide disappeared very rapidly and almost completely. This was due in great part to the simple absorption of the sulphur dioxide by the live plant; to a small degree, to the oxidation of sulphur dioxide in an excess of moist air, and also to that peculiar property of the glass by which it adsorbs the moisture of the air and fixes the sulphur dioxide thereby.

(*b*) That when a mixture of sulphur dioxide and air was left standing in a glass container for a considerable period in a dry atmosphere in diffused light, there was a disappearance of sulphur dioxide—about 10 per cent in about 30 hours.

This was due in part to the oxidation of the sulphur dioxide that takes place on long standing in contact with air, and partly to loss by diffusion. As the carboy stood over night, the gas mixture cooled, and thereby contracted considerably, in which operation the gas mixture was diluted with air to a greater or less extent. Also, in this

test part of the disappearance could be attributed to the adsorptive property of the glass, for although considered dry, yet there was no doubt some trace of moisture present, which would readily be adsorbed by the glass surface, as has already been discussed above.

(*c*) When sulphur dioxide was mixed with air containing moisture to the point of 50 per cent saturation, the rate of disappearance was much greater than in the dry air alone. This was due for the most part to the adsorption of the sulphur dioxide on the glass surface.

(*d*) When sulphur dioxide was mixed with air containing moisture to the point of 100 per cent saturation, the rate of disappearance of the sulphur dioxide was much greater and the disappearance more nearly complete than under any other conditions. In this test, also, the increased amount of moisture accounts, by the neutralizing effect of alkaline from the glass, for a great deal of the disappearance, and also the greater rate of disappearance.

(*e*) When a mixture of sulphur dioxide and air was exposed to the action of direct sunlight, a gradual disappearance of the sulphur dioxide took place, the rate of its disappearance being greatest at those times when the temperature in the carboy was highest. This fact would preclude to a large extent the simple solution of sulphur dioxide by any moisture present, for as the temperature of water ncreases, the solubility of sulphur dioxide decreases to a marked degree. A part of the sulphur dioxide was adsorbed, the amount varying with the amount of water present.

(*f*) In all of these tests both oxidation and absorption took place. In a moist atmosphere both of these took place to a greater degree than in a dry atmosphere.

INVESTIGATIONS OF THE GASES FROM THE DWIGHT & LLOYD SINTERING MACHINES AT THE SELBY SMELTER.

By A. E. Wells.

In the general discussion concerning the conditions in and around the Selby smelter it was shown that all the solid emanations from the furnaces—that is, flue dust and fume—are now removed from the waste gases by filtration through bags. The only emanation that now contaminates the atmosphere is the sulphur dioxide from the sintering machines.

These investigations have been made for the purpose of determining the possibility of reducing the amount of this sulphur dioxide output. A reduction of the sulphur dioxide output can be accomplished either by diverting to an acid plant some of the sulphur-bearing material for the extraction of the sulphur before it is received at the Selby smelter or by reducing, oxidizing, or otherwise recovering the sulphur dioxide produced by the roasting of the material now received.

As stated in another part of this report, the sulphur-bearing material received at the smelter may be classified as follows:

1. California iron-sulphide ores.
   a. Raw sulphide ores.
   b. Preroasted sulphide ores.
2. High-grade gold and silver concentrates and lead-bearing iron sulphide ores.
3. Products from lead concentrators.
   a. Concentrates.
   b. Middlings.
   c. Slimes.

During the last year there was a very small tonnage of the California raw sulphide ores roasted at the Selby smelter. Practically all this material is roasted at an acid plant of the General Chemical Co. for the production of acid, and the roasted ore is then sent to the Selby smelter. No raw sulphides are being used in the charge for the purpose of furnishing fuel for the sintering of the charges on the sintering machines. At no time in 1913 was the amount of the raw sulphides on the charge equal to 10 per cent.

The other classes of sulphur-bearing material can not be handled economically at any acid-manufacturing plant under the present acid practices, because of the rather low sulphur content and of the danger of high metal losses in the treatment.

Thus, as the smelter is not roasting material that could be roasted economically elsewhere, the problem facing us is not so much to determine the possibility of further reducing the sulphur to be roasted as it is to prevent the sulphur dioxide resulting from the present roasting conditions being discharged into the atmosphere. We have attempted to determine whether or not the sulphur dioxide resulting from the oxidation of this sulphur can be treated economically and practically in such a manner that a commercial by-product can be obtained therefrom.

In order to treat these gases successfully in any one of the several possible methods of recovery it is necessary that the concentration of the sulphur dioxide in the gases should be at least 6 per cent SO_2. Thus, before any possible method for the recovery could be considered it was essential to know how great a concentration of sulphur dioxide could be obtained in the gases from the Dwight & Lloyd sintering machines. During January and February, 1914, our work was entirely along this problem, namely, determining the concentration of sulphur dioxide that could be attained and maintained under different charge and operating conditions.

PRELIMINARY STUDY OF CHARGES AND OPERATING CONDITIONS AT SINTERING MACHINES.

Before any experimental work at the machines was started a careful study was made of the character of the material sintered and of the variations existing in the chemical composition and physical nature of the charges and sintered products. The records of the sintering department of the plant were opened to us for that purpose, and we were given all the information at hand concerning the "sintering qualities" and characteristics of the various kinds of charges.

It may be well to point out some of the more important features of the charge conditions before proceeding further, so that the significance of some of the data obtained in the tests may be fully appreciated.

Table 1, giving the monthly average percentages of lead and sulphur in the charge during the year 1913, shows that the amount of lead varied between 20 and 33 per cent and the sulphur between 12 and 14.3 per cent. Not only did the charge composition vary from month to month as shown, but there were even wider variations during the month, as indicated in Table 2.

TABLE 1.—*Monthly average percentages of lead and sulphur in charge in sintering machines during 1913.*

Month.	Proportion of charge.		Month.	Proportion of charge.	
	Lead (Pb).	Sulphur (S).		Lead (Pb).	Sulphur (S).
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
January	20.0	12.9	July	28.8	12.8
February	26.3	12.3	August	25.5	12.2
March	32.6	12.5	September	24.0	12.6
April	33.0	12.0	October	22.0	14.3
May	31.3	12.8	November	26.0	14.2
June	32.9	12.2	December	26.8	13.2

TABLE 2.—*Data showing variations in lead and in sulphur content of sintering-machine charges during certain months in 1913.*

Month.	Proportion of lead in charge.			Proportion of sulphur in charge.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
September	24.0	36.0	16.0	12.6	14.6	11.0
October	22.0	27.0	18.0	14.3	16.8	12.2
November	26.0	36.0	20.0	14.2	15.8	13.0
December	26.8	38.0	22.0	13.2	14.3	12.0

As was predicted and later determined, the variations in the chemical composition of the charge, within wide limits, were not so important in affecting the gas concentration as were the differences in the physical condition of the charge.

A review of the monthly statements for 1913 shows many variations in the proportions of the charge constituents. The average mixtures during April, September, and October are given in Table 3, showing very marked differences in the relative proportions of the constituents.

TABLE 3.—*Average mixtures of charges in sintering machines during each of three months in 1913.*

Material sintered.	April.	September.	October.
	Per cent.	*Per cent.*	*Per cent.*
Concentrates	64.1	34.4	50.2
Raw sulphurets	3.7	9.3	1.9
Preroasted ore	10.7	18.0	35.2
Siliceous tailing	.....	8.4	.....
Crushed quartz	7.3	9.8	6.6
Matte	10.9	8.9	5.6
Fine dust	3.3	11.2	0.5

These figures do not show completely the degree to which the physical nature of the charge has varied, for under the title "Concentrates" is included a wide variety of material ranging in size from coarse lumps of galena (nut size) to very fine impalpable slimes. However, as the greater proportion of the constituents of the charges

is made up of material of approximately the same fineness, it was considered practical to maintain a fairly even physical condition of of the charge by crushing finer the coarser lead concentrates, the jig products, and the matte, and distributing the slimes more equally over all charges. That this would result in more uniform roasting conditions and consequently produce a better product was admitted by the metallurgists of the smelter. It was thought that the ordinary minor variations in the physical condition of the charges that would then be encountered would not cause any very wide differences in the gas concentration.

In order to study the effect of these charge and operating conditions on the gas concentration, and to determine the condition under which the highest concentration or sulphur dioxide could be obtained, the tests to be described in this report were made.

As No. 3 machine was the most recently built, and consequently the contact surfaces of the palettes and wind boxes were the least worn and thus tightest against air leakage, this machine was used in the work. The roasting area of the machine is about 21 feet long, and beneath this length there are two wind boxes into which the air and gases are drawn through the grate bars. An outlet pipe from each box is connected to a pipe leading to a Sirocco fan which maintains a partial vacuum of 6 inches to 12 inches water in the boxes.

PRELIMINARY STUDY OF GAS CONCENTRATION.

To determine the effect of any change of charge or operating conditions upon the general roasting process, it was necessary to determine the sulphur dioxide content of the gases that were actually drawn through the charge at several points along the grate. By these tests also, the points of maximum and minimum concentration were determined, which gave us the basis for subdividing the wind boxes and for the recirculation of some of the gases.

For these determinations a series of 10 holes three-eighths of an inch in diameter were drilled through the side of the wind boxes in a line 8 inches below the line of palettes. By use of a suitable length of glass tubing inserted through these holes and bent upward so that the intake was just below the palettes, a sample of the gases coming through the grates over the holes could be taken out and analyzed. The holes were placed at distances of 1, 3, 5, 7, 9, 12, 14, 16, 18, and 20 feet beyond the ignition point.

Table 4, in which is given the average sulphur dioxide content of the gases coming through the grates at the several points under average charge and operating conditions, shows that the maximum sulphur dioxide concentration was obtained at a point 7 feet from the ignition point, and that for a distance of 7 feet extending from a point 3 feet beyond the ignition point to the end of the first wind

box, the gases averaged 6.5 per cent sulphur dioxide. In the first half of the second wind box, or beginning at a point 12 feet beyond the ignition point, the concentration dropped very quickly so that at the center of the second wind box the sulphur dioxide concentration was only 2.6 per cent, and from that point on dropped to less than 1 per cent at the end.

TABLE 4.—*Average SO_2 content of gases coming through grates of sintering machines at various points under average operating conditions.*

Distance of sampling point from ignition point.	Proportion of SO_2 in gases with average charge.	Distance of sampling point from ignition point.	Proportion of SO_2 in gases with average charge.
	Per cent.		*Per cent.*
1 foot	1.5	12 feet	5.0
3 feet	5.0	14 feet	4.3
5 feet	7.0	16 feet	2.3
7 feet	7.5	18 feet	1.5
9 feet	6.6	20 feet	.9
10½ feet[a]		Sulphur in product	4.5

[a] End of first wind box.

SUBDIVISION OF WIND BOXES AND RECIRCULATION OF PART OF GASES.

A little study of these results suggested that if a partition were placed in the first wind box 3 feet from the ignition point, and the gases from the first 3-foot length (*h*, fig. 5) were separated from the gases from the 7-foot length (*g*, fig. 5) a concentration approaching 6.5 per cent sulphur dioxide could be obtained from section *g*.

This partition was then placed in the box, and from section *g* was obtained an average volume of approximately 2,500 cubic feet per minute at 200° C., carrying an average of 5.5 per cent sulphur dioxide. The concentration varied between 6.5 per cent under the most favorable conditions to as low as 4 per cent under very unfavorable conditions. The details of these variations are given elsewhere in a discussion of the effects of the several conditions.

It was found to be very difficult to keep the concentration of the gases in the outlet pipe up to the average of the gases coming through the grate bars, owing to leaks and to the frequent poor contact of the palettes and wind-box castings.

Having obtained a concentration of 5.5 per cent sulphur dioxide in a part of the gases, it was decided to try to increase that concentration by taking the gases from a part of the second wind box and using these gases as the air supply to section *g* of the first wind box. Thus a partition was placed in the center of the second wind box and the gases from the first half (sec. *f*, fig. 5) were drawn out by a sepa-

rate fan and conducted by suitable piping to a hood placed on section *g* of the first wind box. The hood (fig. 12) was built so as to inclose the palettes so that they would be surrounded completely with the gases and so that air free from SO_2 would be prevented from being drawn into section *g* at leaks between the palettes and the wind boxes.

Thus the space under the roasting area was divided into four sections, *h*, *g*, *f*, and *e* (fig. 5). These sections were well sealed from each other by means of horizontal strips of iron placed on the partition which made contact with the palette castings sliding over them.

Under average conditions, at 160° C., the fan pulled per minute from section *f* fifteen hundred cubic feet of gas containing an average of 2.8 per cent sulphur dioxide. This did not quite supply the air necessary for the proper roasting of the material over section *g*, and some air was drawn in from outside the hood. The average volume of gas drawn from section *g* was about 2,500 cubic feet per minute at 200° C., and the concentration of sulphur dioxide varied between 6 per cent and 8.5 per cent, averaging 7.3 per cent.

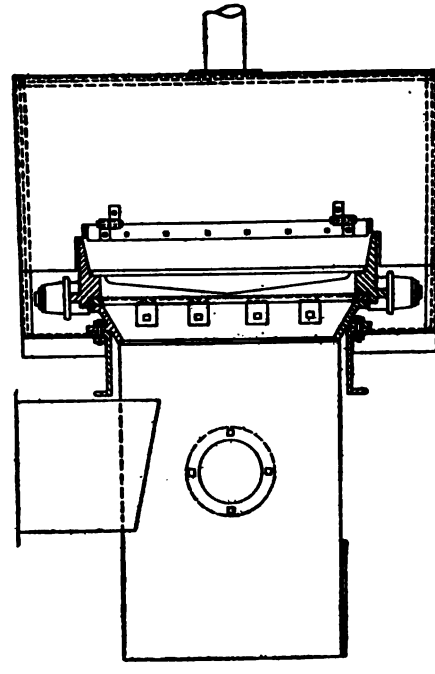


FIGURE 12.—Hood for wind box of Dwight & Lloyd sintering machine.

EFFECT OF VARIATIONS IN CHARGES ON GAS CONCENTRATIONS.

In the two months during which these tests were made a great variety of charge conditions were encountered, not only as a result of our so planning, but as a natural result of the operating condition of the smelter. Charges varied in lead content between 24.4 and 44 per cent, but the average lead content was 34.6 per cent. Sulphur varied between 12 and 15 per cent, averaging 13.5 per cent. The variations in the physical condition of the charges were also very great from mixtures that were rather coarse to fine, dense mixtures, as shown by the following examples. The examples given show the extreme in the charges met with during the tests.

Examples of variation in constituents of charges of sintering machines.

Material.	January, 1914.			February, 1914.
	[a] 14.	[b] 22.	[c] 24.	[d] 24.
"Jigs" or coarse concentrates ... per cent	22	24	.....	.....
Fine concentrates ... do	23	37	70	27
Slimes ... do	.....	.....	.....	39
Crushed quartz ... do	10	.....	4	10
Preroasted ore ... do	24	20	.....	14
Crushed matte ... do	.....	.....	.....	10
Flue dust ... do	6	.....	4	.....
Needles ore or high-grade sulphides ... do	15	19	22	.....

[a] Coarse charge. [b] Medium coarse charge. [c] Medium fine charge. [d] Very dense charge.

Under most charge conditions, other conditions being the same, the general sulphur dioxide concentration at the several points along the hearth was rather close to the values given in Table 4.

Interesting results were obtained from a charge made up as follows:

Constituent.	Per cent.
Fine concentrates	60
Preroasted ore	18
Needles sulphide ore	6
Siliceous sulphides	13
Flue dust	3

The charge contained 34.5 per cent lead and 14 per cent sulphur. This mixture was fine, but very even. The rapid elimination of sulphur from the charge over the first wind box is shown in Table 5. With a charge of this character fairly constant gas concentrations can be maintained at the several points along the machine.

TABLE 5.—*Concentration of SO_2 at various points along the hearth with a special favorable charge.*

Distance from ignition point.	Proportion of SO_2 in gases with favorable charge.	Distance from ignition point.	Proportion of SO_2 in gases with favorable charge.
	Per cent.		*Per cent.*
1 foot	3.2	14 feet	1.0
3 feet	7.8	16 feet	.....
5 feet	11.2	18 feet	.5
7 feet	6.5	20 feet	.....
9 feet	5.2		
10½ feet [a]	.....	Sulphur in product	3.2
12 feet	2.5		

[a] End of first wind box.

The data from Tables 4 and 5 are shown diagrammatically in figure 13.

In sharp contrast to a charge of this even condition, a charge similar to that of January 8 stands out with interesting and indicative results.

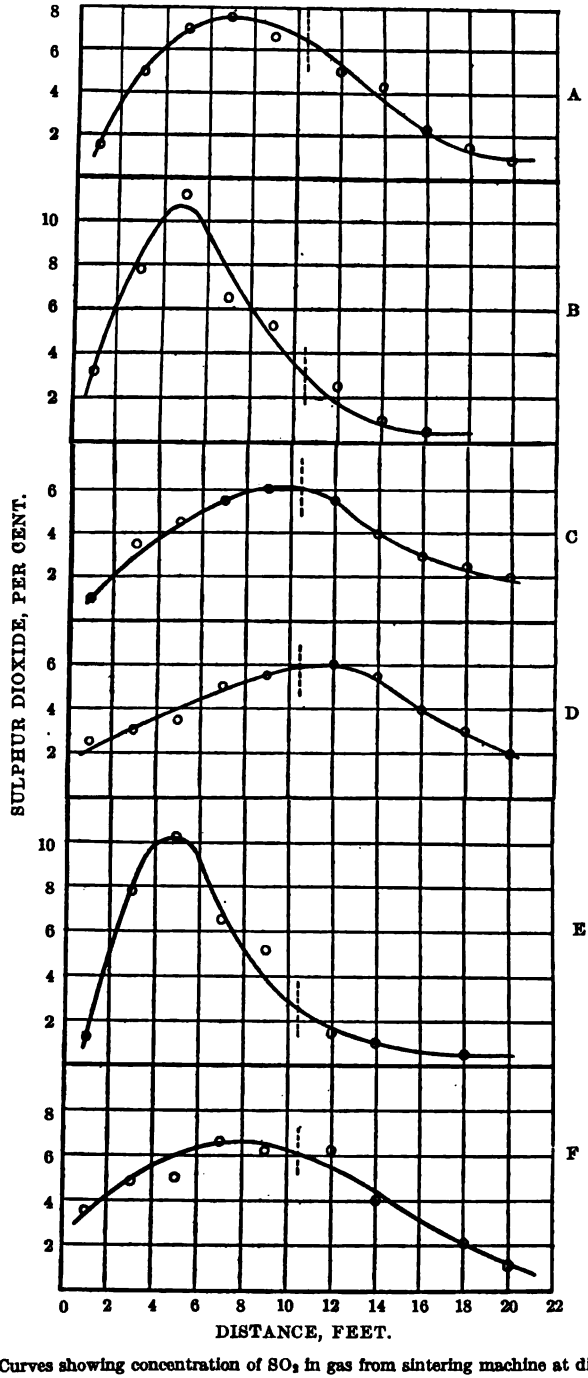


FIGURE 13.—Curves showing concentration of SO_2 in gas from sintering machine at different distances from ignition point: A, results with average operating conditions; B, results with a special charge; C, results with a coarse charge; D, results with a dense charge; E, results with good ignition and good product; F, results with poor ignition and poor product.

The charge was made up as follows:

Constituent.	Per cent.
Lead jig concentrates and slimes	35
Preroasted sulphurets	29
Flue dust	8
Needles ore	8
Crushed quartz	11
Crushed matte	9

It contained 31 per cent lead and 13.7 per cent sulphur. With this charge it was impossible to maintain even conditions in moisture content, ignition, or wind pressure, and the result was that the sulphur dioxide concentration at any point varied greatly. Furthermore, it was impossible to attain a concentration higher than 6 per cent SO_2 at any point (see Table 6). At times the SO_2 elimination would be good and the product excellent; at other times the material would hardly roast and would not sinter. The trouble was due almost entirely to poor mixing of the material in the charge. The coarser particles of the charge were separated from the finer in the feed bin and especially in the drop into the hopper over the machine. The conveying and mixing device for the machines was to a great degree inadequate to meet the conditions of a charge similar to the above. With a charge in which the material is of approximately the same physical character, the present mixing schemes are very satisfactory, and a charge of this character gives excellent results. With a dense charge, results were obtained similar to those given in Table 6. No high concentrations were attained.

TABLE 6.—*Concentration of SO_2 at various points along the hearth with two types of charge.*[a]

COARSE CHARGE.

Distance from ignition point.	Proportion of SO_2 in gases.	Distance from ignition point.	Proportion of SO_2 in gases.
	Per cent.		*Per cent.*
1 foot	1.0	14 feet	4.0
3 feet	3.5	16 feet	3.0
5 feet	4.5	18 feet	2.5
7 feet	5.5	20 feet	2.0
9 feet	6.0		
10½ feet [b]		Sulphur in product	5.9
12 feet	5.5		

DENSE CHARGE.

1 foot	2.5	14 feet	5.5
3 feet	3.0	16 feet	4.0
5 feet	3.5	18 feet	3.0
7 feet	5.0	20 feet	2.0
9 feet	5.5		
10½ feet [b]		Sulphur in product	5.4
12 feet	6.0		

[a] See curves in fig. 13, C and D.

[b] End of first wind box.

Table 7 shows the manner in which the rate of sulphur dioxide elimination can be varied by the manner of ignition. These figures were obtained from a charge of the following character:

Constituent.	Per cent.
Fine concentrates	46
Crushed quartz	8
Preroasted ore	26
Flue dust	9
Needles ore	11
Analysis.	
Silica (SiO_2)	8.5
Iron (Fe)	24.5
Lead (Pb)	33.5
Sulphur (S)	14.2

In one case the ignition was correct and in the other the ignition was too hot, causing the material to semifuse and bake on top, which prevented the air from penetrating the charge.

TABLE 7.—*Concentration of SO_2 at various points along hearth with good and with poor ignition.*[a]

GOOD IGNITION AND GOOD PRODUCT.

Distance from ignition point.	Proportion of SO_2 passing through grates.	Distance from ignition point.	Proportion of SO_2 passing through grates.
1 foot	1.3	12 feet	1.5
3 feet	7.8	14 feet	1.0
5 feet	10.2	16 feet	.....
7 feet	6.5	18 feet	.5
9 feet	5.2	20 feet	.....

POOR IGNITION AND POOR PRODUCT.

1 foot	3.5	12 feet	6.2
3 feet	4.8	14 feet	4.0
5 feet	5.0	16 feet	.....
7 feet	6.6	18 feet	2.0
9 feet	6.2	20 feet	1.0

[a] See curves in fig. 13, E and F.

It may be well to mention some of the other factors affecting the roasting process, and thus the sulphur dioxide concentration. Although it has not yet been mentioned in this report, the proportion of moisture in the charge is of prime importance, too much or too little moisture being equally fatal to good results. It is very certain that a device for the intimate mixture of the water with the charge, such as a "mixing table" as used at many smelters, would serve to eliminate some of the irregularities due to the moisture content.

It is not necessary to state that the wind pressure must be regulated to the character of the charge for a constant gas concentration,

which is another reason for desiring more perfect mixing of material, etc.

The depth of the charge on the grates is another factor influencing the gas concentration. During these tests we found that dense charges gave more satisfactory results if the depth was reduced from 4 to 3 inches, and even to 2 inches, if properly ignited. With a 4-inch layer the pressure required to draw the air through the charge caused excessive air inleakage through contact surfaces, etc.

It may be thought that undue attention has been given to the determination of the variation in the sulphur dioxide content of the gases at the several points along the machine. It was found, however, that these determinations were of great importance. By finding the conditions under which the sulphur dioxide values were like those given in Table 4 and approached the ideal conditions as shown in Table 5, not only was the concentration of the gases from section 2 higher in sulphur dioxide and contained a larger proportion of the total sulphur dioxide, but also the sintered product was greatly superior and lower in sulphur.

Provided that the ignition was adjusted to suit the conditions, there was no difficulty in maintaining a gas concentration greater than 7 per cent in the exit pipe from section 2 from charges carrying between 30 and 44 per cent lead. Of course the higher the lead sulphide content the more difficult it was to get proper ignition. The average sulphur dioxide concentrated in the gases when a charge carrying 36 per cent lead and 13 per cent sulphur was being roasted was as follows:

Charge, 100 tons per day, at 13 per cent sulphur.

Product, 90 tons per day, at 4.5 per cent sulphur.

Sulphur eliminated, 9 tons per day, or 12.5 pounds per minute.

Sulphur dioxide, 25 pounds per minute.

The average volume of gases from section 2 (*g*, fig. 5) was 2,500 cubic feet per minute, at 200° C., or 1,500 cubic feet per minute at 0° C. Thus the sulphur dioxide volume was 1,500 times 0.073, or 110 cubic feet of sulphur dioxide at 0° C., or 19.5 pounds of sulphur dioxide per minute, equivalent to 78 per cent of the total sulphur dioxide eliminated from the machine.

When the lower values, 6 per cent, were obtained, the charge was very dense, containing a large proportion of slimes, or the lead sulphide content was so high that it was impossible to get good ignition. Both conditions caused poor roasting results as well as poor gas concentration.

Throughout all the work it was clearly evident that all the conditions desired for maintaining a concentrated gas are the same conditions desired for making more perfect the roast and sinter. Thus, as the sintering conditions are improved at the plant, the conditions

for maintaining even higher gas concentration will undoubtedly be reached.

In connection with the scheme of recirculating the gases from one part of the machine through another, not only do we decrease the total volume of air used and thus increase the resulting gas concentration, but we are also able to filter out the fume present in the first volume. While rehandling the No. 3 (*f*, fig. 5) gases through No. 2 (*g*, fig. 5) the surface of the charge, after leaving the hood, was coated with white fume filtered from the No. 3 gas.

PROPOSED SCHEME FOR OBTAINING A GAS OF HIGH SULPHUR DIOXIDE CONTENT FROM A BATTERY OF MACHINES.

From the fact that we were able to get a concentration of 7.3 per cent sulphur dioxide by recirculating No. 3 [a] gases through No. 2, we are justified in stating that by taking all or a part of the gases from No. 4 and circulating these through No. 3 and the resulting gas from No. 3 through through No. 2, the concentration can be raised to at least 8 per cent, and in so doing we will have over 85 per cent of the total sulphur dioxide in a volume of 1,500 cubic feet (0° C. and 760 mm.).

To do this would require three small fans per machine, or the same result could be accomplished in the battery of three machines as follows, namely, one large fan could be placed to draw the gases from the No. 4 sections of all the machines, which would be discharged into a header pipe, from which other pipes would conduct the gases into hoods placed on the No. 3 sections. Another fan would draw the gases through the charges on No. 3 and discharge into header pipes over No. 2. A third fan would draw the gases through the No. 2 sections and discharge into the apparatus placed for the treatment of the gas. A fourth small fan would be required to draw out the gases from the No. 1 sections, and discharge them into a flue, as these gases are very dilute and contain practically all the water that was present in the charge. As there is now one fan for each machine, this scheme could be installed with the purchase of only one fan.

The chief objection to a scheme such as the above is that the shutting down of a fan for repairs, etc., might mean the stopping of the whole battery of machines. This objection could be overcome by suitable dampers in partitions and by-passes between the header pipes.

Another objection to this scheme is that the same number of fans would be required while only one machine was being operated as

[a] For an explanation of the numbers referred to in this section, see page 67.

when three were in operation. However, the greater part of the time there will be two or three machines operating, unless the smelting practices of the plant change.

One desirable feature of this scheme is that in the circulation of the gases through the charge the fume and dust is filtered out, so that the only dust and fume that will require removal from the final gas volume will be that drawn through No. 2 section, which is very small.

SUMMARY.

Summarizing the results of the investigation briefly, it may be stated that under the charge and operating conditions consistent with good roasting and sintering results, we have obtained at least 75 per cent of the total SO_2 from the machines in a gas volume that had an average concentration of 7.3 per cent SO_2.

We have divided the roasting area of a machine into four sections, which, beginning at the ignition part, we have designated as follows:

Section.	Length in feet.
1	3
2	7
3	5
4	5

From section 2 alone we have drawn out a volume of gas containing 5.5 per cent, or 55 per cent of the total SO_2 produced in the machine. From section 3, we have obtained a gas containing 2.8 per cent SO_2. By conducting the gas from section 3 into a hood placed over section 2, we have raised the concentration of the gases in the exit pipe from section 2 to an average content of 7.3 per cent of SO_2. This gas then contained 78 per cent of the total SO_2 eliminated by the machine.

In order to gain these results, we have found it necessary to maintain certain conditions, the most essential of which are as follows:

1. The variations in the physical condition of the charges should be kept within limits that will exclude very coarse lead concentrates, coarse raw matte, and lumpy materials. This limitation would also exclude the presence of an excessive proportion of lead slimes in the charges.
2. The constituents of the charges should be intimately mixed.
3. The charges should contain the correct moisture content, which should also be intimately mixed with the other materials.
4. The ignition of the charges should be carefully watched.

All of these conditions are equally as essential for the best roasting and sintering results for the production of a gas of high concentration, and the attainment of these conditions is well within the range of smelter operating practices.

The chemical composition of the charges may vary within the wide limits that will still allow of a successful roast and sinter, and, if the conditions above mentioned exist, the high gas concentration can be realized.

Furthermore, we have concluded that should it be desirable, 85 per cent of the total SO_2 can be concentrated in a volume that will contain a concentration of at least 8 per cent of SO_2. This, however, would call for a rather more complicated arrangement of fans and air-pipe lines, but would still be practical.

With a concentration of 7 to 8 per cent it is possible to apply a commercial scheme for the recovery of sulphur dioxide, either as liquid sulphur dioxide, sulphuric acid, or sulphur.

A DETAILED STUDY OF STATEMENTS OF RESIDENTS OF THE SELBY SMOKE ZONE AS REGARDS THE PRESENCE OF A NUISANCE IN THE AREA.

By C. B. Dutton.

STATEMENT OF SUBMITTAL.

I submit herewith the following report of the results of my investigation in and around the city of Benicia, Cal., with respect to conditions reputed to result from the operation of the lead smelter and refinery located at Selby, Contra Costa County, and owned by the Selby Smelting & Lead Co., of San Francisco.

INTRODUCTION.

The investigation was made with the idea of developing, so far as possible, evidence along the lines of the findings required to be made by the stipulation appointing the commission. Under the terms of this stipulation the commission is to report to the parties "concerning the operation of the defendant's plant with respect to emission of deleterious or injurious smoke, fumes, and gases, if any, therefrom, and the effect, if any, thereof upon the territory alleged to be affected," and to find (*a*) whether the defendant's contention is true that it is not operating its plant "in a manner to violate the decree heretofore duly given," or (*b*) whether the defendant is "operating its plant in such manner as to produce smoke, fumes, and gases offensive to the senses, or destructive to the property of people residing in said district of Solano County, or so in any manner to be violative of the said injunction."

The material questions, then, were whether or not the Selby plant still constituted a public nuisance within the meaning of that finding and decree, and to what extent, if any, the operation of such plant interfered with the comfortable enjoyment of life and property, injured animals and vegetation, or depreciated the price of crops.

SCOPE OF INVESTIGATION.

The investigation covered all of the outlying ranches or farms within the smoke zone, so called, and a considerable part of the city of Benicia. Effort was made to see all the ranchers, but with incom-

plete success, as several of them could not be found at home, despite repeated trips to the premises. The great majority of the ranchers, however, were interviewed.

Before taking up the work, I proceeded to Vallejo and had several conferences with Mr. H. J. Widenmann, one of the board of county supervisors, with Mr. Joseph M. Raines, the district attorney of Solano County, and with Mr. J. R. Glendon, another member of the board of supervisors, at Benicia. I discussed with them the manner in which it was proposed to cover the ground, and found that the plan met with their approval. It seemed best to all of us to cover the outlying ranches before taking up the work in Benicia, and this was accordingly done.

At the outset it was realized to be hardly possible to make a house-to-house canvass of the entire city of Benicia. The most practicable plan seemed to be to make a canvass of the business men of the town, and also a house-to-house canvass along the water front, where the smoke was alleged to be the worst. Supplementing this, it seemed desirable to have a selected list of representative citizens, whose views could be considered as fairly expressing the sentiment of the community. This plan of procedure met with the approval of Mr. Gould and Dr. Franklin of the commission, and of Supervisors Glendon and Widenmann, District Attorney Raines, and of Mr. Crooks, the president of the board of trustees of Benicia. Mr. Crooks undertook to give me a list of the business men of the city, and requested Mr. Johnston, who is a member of the anti-Selby fumes organization, to give me a list of representative citizens. Mr. Glendon also agreed to give me a list of some 40 or 50 names. Some 200 names, counting duplications, were thus furnished to me. I interviewed some 150 persons, most of them being named on these lists. I did not stick too close to these lists for obvious reasons, but found them to have been fairly selected and to include the really representative citizens of the city. So far as the main part of the city of Benicia is concerned, the testimony seemed so uniform and consistent that it hardly seemed necessary to prosecute the inquiry further. Accordingly, with the approval of Mr. Gould, the taking of further testimony was stayed until the results of these interviews could be compiled.

The situation with respect to nuisance or damage resulting from the smelter operations seems to separate conveniently into two divisions, and is so treated herein, the one relating to conditions on the ranches outside of Benicia, and the other relating to conditions in the city proper, although the questions at issue are one and the same.

INTERVIEWS WITH RANCHERS.

Some 34 ranchers, or their wives, were interviewed, comprising the majority of those engaged in ranching in the affected district.

SMELTER SMOKE, DUST, FUME, AND GASES.

With respect to the smelter smoke, I found it impossible to get any definite idea as to the frequency with which the smoke has come either during this present year (1913) or during 1912. The best that could be done was to get some general statement from which inferences could be drawn.

CONDITIONS DURING 1913.

With two exceptions, all conceded that there has been an improvement this year; in most cases a considerable improvement. One exception was a farm hand (witness No. 7) who has lived in the district for two and one-half years, and whose testimony was contradicted by that of his employer (witness No. 6). The other exception was witness No. 11, who claims that conditions are just as bad as ever. The great majority declared that conditions were nothing like they have been, "not near as bad," "not near as frequent," "much better," "nothing like as bad," etc., being some of the typical expressions of opinion. Only one person claims not to have noticed the smoke at all this year. While the others claim to have noticed it to some extent, it has only been occasionally. Witness No. 16, for example, has been unable to get a "strong whiff of the smoke" during the entire year, though he has been constantly on watch, so as to be able to file a complaint of violation of the injunction against the smelter. The majority seem to feel that existing conditions are satisfactory; that is, do not afford ground for serious complaint. Witnesses Nos. 4 and 11 are the only ones who complain that the smelter smoke is still a nuisance. Such smoke can not be much of a nuisance to the former witness when he has rented this same ranch for 18 years, and when he has given the smelter company a smoke easement over it. Witness No. 4 was influenced by hope of getting the smelter company to purchase his lands in making a statement of this sort, as a perusal of the testimony will show, and even this witness concedes that the smoke is "not so bad" this year.

Only 4 persons out of 34 claim that the smoke when noticed is as strong or as disagreeable as it was three or four years ago. These are witnesses Nos. 8, 18, 22, and 11. Witnesses 11 and 15 are the only ones who claim to have had the smoke during the present year with any degree of frequency. The others make no assertion of having had it more than a few times this year, though just how many

that means it is impossible to state. All efforts to get definite figures were futile. It can not have been very many, or conditions would unquestionably have been declared to be bad, judging from the comments repeatedly made in my presence.

CONCLUSIONS AS TO CONDITIONS IN 1913.

Although the lack of data as to the exact number of times the smoke has been observed is to be regretted, yet it is impossible to conclude from the testimony as a whole, and the manner in which it was given, that the smelter has constituted a public nuisance during the present year with respect to the emission of sulphurous gases, noxious fumes, or smoke.

I found no evidence of injury to health at the present time due to smelter operations. The daughter of witness No. 15 claims that the smoke injured her health in the past. Several women spoke of being made sick when the smoke used to come, but that does not appear to have occurred during the present year.

I am convinced that it can not reasonably be found from the testimony, as a whole, that the smoke, gases, or fumes emitted have been so offensive to the senses as to interfere with the comfortable enjoyment of life and property during the present year. The testimony does tend to establish such a condition three to seven years ago.

CONDITIONS DURING 1912.

As regards the year 1912, the testimony is not so unanimous. Five of these 34 persons claim that conditions were bad in 1912, "about as bad as they ever had been," while 5 more state that the year was an improvement over preceding years, but still was "not as good as the present year." The remaining 24 link the present year with last year and claim that the smoke has not been as bad for the last couple of years, some specifying two years and others three years, although the majority say the former. Only one person out of this number claims not to have observed the smoke at all, either during 1912 or 1913, while one other claims not to have observed it during 1912, but to have noticed it a few times in the month of August of this year. With these two exceptions, all of these 34 persons claim to have noticed the smoke at some time or times during both years. The same inability to give any idea as to the frequency of the smoke was found to exist.

The only conclusion to be drawn is that the great majority of those living on the ranches did not find the smoke during 1912 to be a matter of public nuisance or such as to interfere with the comfortable enjoyment of life and property. This for the reason that the great weight of the testimony is the same for the two years. Five persons

instead of two persons claim to have found conditions as bad as ever, while five more found them worse than during this year. These 10 persons do not live in any one section of the zone affected by smelter smoke, but are scattered throughout the region. Witness No. 18, for example, claims that the smoke came just as often and was just as strong during 1912 as ever, while his neighbor, across the road (witness No. 19), says that in the last three or four years she has been bothered very little, and has not "smelled any smelter odor for a long time." Witness No. 16, whose ranch adjoins that of witness No. 18, stated that 1912 was an improvement and was "not half as bad" as before. Witness No. 8 claims that the smoke was as frequent as ever last year, but witness No. 5 on the next farm found it "better than before." Weighing all the evidence and taking into account conflicts such as this, it is not believed that the evidence establishes the existence of a nuisance during 1912 any more than during 1913.

DISCUSSION.

While a comparative mode of expression is unsatisfactory, it seems to me that a fair interpretation of the evidence, taking everything into consideration, is that when the statement is made that conditions are "not as bad," "are nothing like as bad," etc., it is practically equivalent to saying they are not bad. This would not be a safe conclusion generally, but I believe it to be in this particular instance. If conditions had been found bad, there would be no hesitation in saying as much. If the smoke came with considerable frequency and constituted a serious annoyance, a positive nuisance, it would seem that some very definite idea would exist as to the extent of the nuisance; that there would be some distinct recollection on the subject. This interpretation does not mean that the smoke has not been observed at all, but does mean that it has not been observed to that extent and degree which would justify a finding that it constituted a public nuisance.

I tried repeatedly to get some statement as to the number of times per week or month that the smoke had been observed either during 1913 or 1912, but without success, the answer usually being that it all depended upon the wind; the smoke might come for two or three days at a time, and then not come again for a couple of weeks, for example, so that they could not tell definitely. When I found they were honestly unable to give any idea, I refrained from making suggestions as to the number of times, which would call forth a purely perfunctory assent, and not give a true index to conditions.

There is a feeling that exists generally, both in the outlying district and in Benicia itself, which must be taken into consideration in passing upon this evidence. There is a good deal of skepticism as to whether any improvement has been effected, particularly with respect to

injury to stock, in spite of the fact that the smoke is not observed as often. This manifests itself, for one thing, in the unwillingness of a number of farmers to leave horses out over night, and for another, in the belief that the winds are carrying the smoke in a different direction. This feeling is that after years of fighting they have obtained a "hardly won" advantage over the smelter, and it is necessary for them to retain it for their own comfort and security. It is felt that if the smelter is found not to be a nuisance by the commission, then the plant, being relieved of the burden of the injunction, will resume operations on the old scale, and conditions will soon be as bad as ever. This feeling is quite prevalent, and is openly expressed by many. It is important to keep the existence of such a feeling in mind in considering the transcript of the evidence, as it undoubtedly manifests itself to some extent in the hesitating and equivocal forms of expression employed to describe existing and past conditions.

As a result of this feeling, a considerable prejudice was found to exist toward the commission, both in Benicia and the district outside, the sentiment being that the commission was appointed to "whitewash" the smelter. It was necessary to counteract this impression, and to devote some time to a friendly chat explaining the purpose of the commission, the manner in which it was at work, and emphasizing the fact that this commission was equally the representative of each party to the controversy. So general was this prejudice that it was soon found advisable to make some such explanation in advance before attempting to question. The fact that Federal employees were connected with the investigation seemed to assist to some extent in gaining the confidence of the persons interviewed, and in counteracting this initial prejudice.

There is the same variety of opinions with respect to conditions that would be found upon almost any subject. But considering the weight of the evidence for these two years, and taking into consideration the existence of such a feeling as that referred to, and the relative credibility of the witnesses, as it impressed itself upon me, I believe the conclusions above expressed are fair and reasonable.

SMELTER SMOKE AND OIL FUMES.

The Selby Company has been claiming that the more offensive odors complained of in the past were attributable to the oil works located just below the plant, at a place called Oleum. While the testimony is not sufficiently detailed, and could not be so obtained, to permit of definite conclusions, yet it does tend to confirm this claim to some extent. The stills at this oil works were capped in July, 1910, but some trouble was experienced with them up to July, 1911, or thereabouts. It is claimed that it was the custom to empty these stills

sometime during the night or early morning and that the odors complained of are the highly penetrating gases given off in the distillation of crude oil for asphalt manufacture. The smelter, in the meantime, has been operating on the same scale, and has been turning out increasing and not decreasing quantities of sulphur. Keeping these facts in mind, the following condition appears suggestive, at least.

The majority of ranchers find that conditions have been much improved in the last two or three years. A little more than two-thirds are of this opinion. More than half of those who testified concerning the time when the smoke came noticed it worst during the night or early morning hours. Eleven identify the smell as similar to that of sulphur, while 12 claim it as something else, most of them calling it "a nasty smell," "a suffocating odor," "an awful smell," "resembling a dead cat," " rotten-egg smell," etc., while five can not identify it. It seemed to me that some of those who called it a sulphur smell did so because it was suggested to them by me, after they had failed to give any opinion at all, and others because the common talk has been of sulphur fumes. For instance, witness No. 19 first said that the offensive odor was like "a dead cat," and in the next breath stated that it was like burning sulphur. In nine cases the fumes "used to bring on nausea or sickness," and in four others "produced a choking, suffocating feeling."

While it is true that the smelter smoke alone would probably be most offensive in the early morning, owing to the air being heavier and preventing the smoke from being diffused as rapidly as at other times, yet it seems difficult to believe that sulphur dioxide could have been present up to two or three years ago to the extent complained of without causing a great deal of damage. Yet no such damage is established. The smelter has continued to operate since on practically the same scale without a like degree of complaint, so that, while the testimony does not throw as much light on the question as could be wished, and this because the witnesses were not close enough observers, and also because they would not submit to the grilling examination or questioning necessary to follow up all these different leads, it does seem to suggest that something was present in the atmosphere up to about two or three years ago that had a different odor and effect from the characteristic smelter smoke. The effects attributed to this condition which prevailed at that time seem quite different from those commonly attributed to sulphur gases or sulphuric-acid fumes, and differ as much therefrom as the description of the odor differs from what would be expected as a description of sulphur gases or sulphuric-acid fumes.

A detail noted in this connection is that practically all of those testifying complain of irritation of the mucus surfaces of the throat, resulting in a cough or "hack." This is a condition that might and would

probably result from the presence of sulphur-dioxide gas in appreciable quantity. Whether allyl sulphide or any ethylene hydrocarbons alleged to be found in air affected by oil-refinery gases produced the more offensive odors then complained of is something for the chemists to determine. It can be said at least that there is sufficient in the testimony to justify some effort to determine this as a fact, if the condition still existed.

The capping of the stills has not eliminated all complaint, however, as witnessed by the fact that only one person claims not to note the smoke at all, and indicates that the oil fumes were not the whole nuisance complained of. It is possible that these oil fumes still continue to come. Little or no evidence confirmatory of this was obtained. Eight out of 34 persons claimed to have recognized "oil odors." Six of these could not identify the odor, while the others described it as "a crude-oil smell" and as "resembling the odor at the oleum plant," respectively. No idea could be obtained of the number of times these fumes were observed. It appeared to be the consensus of opinion that they were noticed much less frequently than the smelter smoke, though still observed to a limited extent. These oil odors were not claimed to be offensive, and I was impressed that some of the claims of ability to detect oil smells were due merely to the fact that such smells were claimed to exist, that is, to the disinclination of some to admit ignorance of something on which others claim to be informed.

The smoke is not alleged to hang about for a day or for hours now, as it did formerly, which would make it appear that with the elimination of the oil fumes the sulphurous acid gas is not as annoying to the majority of people, assuming that the irritation and hacking cough before were due to smelter smoke. This tends to the conclusion that the more offensive odor then observed constituted a considerable part of the nuisance alleged. Even though the sulphurous acid gas is noticed at varying times, it seems to be so diffused and come in such small bodies that it is not the subject of bitter complaint, as was the smoke of a few years back, save in a few instances. These instances may be accounted for by the fact that some people seem to be more sensitive to it than others, on account of throat weakness, etc.

INJURY TO ANIMALS.

With the exception of witness No. 1, none of the ranchers interviewed claimed to have lost any stock from the smelter during the present year. This witness did not make a positive claim that the death of his three cows was attributable to the smelter, but made a statement intimating as much, in such a way as to indicate that he did not know what their death was due to. I have recently been informed by witness No. 12 that one of the three colts which he

claimed to have been "smelted" three years ago died within the past two weeks. As he has two other colts in the same condition, it should be possible to learn something of the cause if an examination is made by a competent veterinarian. With six exceptions, no one claims to have had any trouble with horses since the blast-furnace bag house was constructed and placed in operation.

DAMAGE TO HORSES.

Witness No. 8 claims to have had a colt "smelted" about three years ago; witness No. 12 claims to have had three colts "smelted" three years ago; and witness No. 9 claims to have had three colts "smelted" about four years ago. Witness No. 1 claims to have lost three horses in 1910, and witness No. 24 two horses about four years ago. This constitutes the extent of the damage to horses that is claimed by the ranchers interviewed in the past five years.

It is only fair to state that numbers of the farmers still refuse to leave their horses out at night for fear of further damage from lead poisoning. In the last year or two a few of the farmers have been leaving them out more. Witness No. 13 has been placing colts out for three years on the tule just across from the ranch of witness No. 11, stating he "did it for a test," but has noticed nothing wrong. The latter has had his colts out this year and has not observed anything out of the way. Witness No. 18 has put his horses out this year with no ill effects. Witness No. 20 placed two colts out last year and one out this year with no ill effects. Witness No. 12 has been leaving his colts and horses out, and states that the horses "smelted" six or seven years ago are not getting worse, and up to the time of the death of the one colt the colts continued about the same.

It is impossible to prove or disprove what these witnesses claim about the colts and horses lost in prior years, so that their statements must be weighed in the light of the facts developed. Witness No. 5 told me he was satisfied that no damage to stock had been done since the bag house was installed, as he would have heard of it if there had been any. He had not learned of his neighbor (witness No. 8) having suffered any losses subsequent to that time. The fact that several of these witnesses had suffered horse damages, which the smelter had paid for, lends weight to their claims.

It is perhaps as appropriate to state here as any place that the smelting company in past years has settled for horses on the claim of the owners without making any thorough investigation. This came to me from a number of widely different sources, and I am convinced it is true. I was told of instances where horses died from natural causes, and yet the company made a liberal settlement for their alleged poisoning. Again, the purchase of lands by the smelter, which is taken to be an admission of continuing injury to such lands

and the payment of damages for the death of horses naturally awakens a disgruntled feeling on the part of those who consider that they are similarly situated but did not receive like liberal treatment.

DAMAGE TO COWS AND OTHER ANIMALS.

Witness No. 1 claims to have lost 50 cows in the four-year period from 1909 to 1913, the greatest losses occurring in 1910 and 1911. He lost some cows in 1912, and three cows of his herd died this year after the sale of such herd to his lessee. These cows had a cough, suffered loss of appetite, and got poorer and poorer until they died. He did not have any of the cows examined by a veterinarian. The Selby Co., however, claims to have bought one of these cows and to have had an autopsy made, with the result that traces of tuberculosis were found. They claim to have obtained an affidavit from the witness to the effect that the other cows which had died were similarly affected, and further claim that since this autopsy he has not said very much to them about smelter injury to his herd.

The smelting company further claimed that the milk from the ranch of this witness had been barred from the city on account of tuberculosis. Inquiry at the office of the board of health failed to confirm this statement. It was learned, however, that the herd had been examined by the milk commission of the county medical association and a certificate given. The milk as a result came to San Francisco as certified milk and was examined by the board of health officers. It was found that the bacteria content of the milk was increasing, and as the witness failed to comply with some of the requirements of the board, the certificate was taken away and the milk no longer examined. The milk still enters the city as market milk but not as certified milk. During the period that examination was made of the milk no traces of tuberculosis were found. This does not mean that tuberculosis was not present in the herd, as I was also informed that the milk from a tubercular cow is not necessarily tuberculous. The description of the condition of these cows prior to their death would seem to suggest tuberculosis.

Witness No. 24 claims to have had trouble with his dairy herd in 1910 and 1911, but to have had none in the last two years. In the two years mentioned he lost about 14 cows. These cows began to get thin and poor and fell away until they died. He asserts it was not tuberculosis, as the cows did nor fall away enough for that, and went down too rapidly. The cows "coughed and got poor." The condition described would seem to indicate tuberculosis, and, as a partial confirmation of this, witness No. 44, a butcher in Benicia, stated in the course of my interview with him that some three years ago he bought some cows from witness No. 24 and found the cows to be tubercular. He told the latter of this finding and declined to buy

any more cows from him, although one of the sons has been in several times since trying to sell some. Witness No. 44 also asserted that within five years there has been a considerable amount of tuberculosis among cattle in and around Benicia. None of these cows was examined by a veterinarian.

Witness No. 20 claims to have lost a number of cows prior to 1908 and to have lost one cow in each of the years 1911 and 1912. These cows dried up and seemed to do so poorly that he killed them. He opened one of them and found "the throat filled with a black substance as far as the brisket." This he seemed to think was a "lead" or or other deposit from the smelter. Witness No. 25 also claims the loss of four cows four or five years ago (the date not being fixed), along about the time they put in the bag house. These cows coughed but remained fat. None was examined by a veterinarian.

Witnesses Nos. 16 and 18 both claim to have had trouble with sheep during the past five or six years. The latter still has a few sheep, but the former sold his flock a year ago. The first witness claims to have suffered $4,000 loss in two years' time, namely, 1911 and 1912. Neither had the sheep examined by a veterinarian, although witness No. 26 declares he "opened one or two of the sheep and found the lungs filled with a black substance just like the horses that had died years before." These sheep, according to this same witness, were all short-winded and would "hang behind the flock when run by a dog, falling down if urged for any distance." The other witness referred to asserts that the sheep did "poorly," became "thin and poor," and were "dying off all the time." His claim was that he never found the dead sheep in time to have an examination made. The fact that the sheep did not multiply in anything like the proportion they should theoretically was cited by both as an indication of smelter damage.

CONCLUSION AS TO DAMAGE TO STOCK.

At the time of the trial of the injunction suit the damage to horses was one of the chief points made against the smelter. This damage extended throughout the so-called smoke zone, and was both general and continuous. Sheep and cows were declared by most witnesses to be immune, although two witness claimed at the trial to have had cows "smelted," losing three cows altogether. Witness No. 12 claims now to have lost a number of cows years ago, which he believes were "smelted," but this fact was not developed at the trial, which seems a little strange. Witness No. 11 claims to have lost a number of sheep in 1906, but not earlier, and makes no mention of any loss since.

It is rather a peculiar circumstance, then, that there should be more claim of damage to cows and sheep since the bag house was put in operation than there was before. It would not seem that any of the

cow losses suffered in the past five years can be attributed to the Selby smelter. The description of the symptoms in most instances suggests tuberculosis, and the fact that tuberculosis was prevalent in the region tends to strengthen this conclusion.

The claims of witnesses Nos. 16 and 18 regarding sheep losses are not convincing as to smelter damage.

Summing up the evidence on the question of destruction or injury to stock, the great weight of evidence is to the effect that no damage has been done to stock (not including horses) since the bag house was installed. The death of the three cows belonging to witness No. 1 is the only claim of injury during the present year. This claim is not convincing in the light of all the testimony, since it is difficult to see why his place should be injuriously affected while other places in the same neighborhood and similarly exposed were immune. The only conclusion that can be reached from the statements of the farmers is that the smelter is not emitting at the present time any fumes that are a cause of injury or death to stock.

The losses of cows suffered by witnesses Nos. 1 and 20 and the sheep losses of witnesses Nos. 16 and 18 are the only claims of injury to stock last year. This evidence is not convincing as to damage or injury during 1912, and it is not believed such evidence of isolated damage can justify a finding of violation of the injunction in this respect during that year.

There does not appear to be any evidence sufficient to warrant the conclusion that the smelter has been a cause of damage to stock since the blast-furnace bag house was installed.

With reference to the damage to horses, it is more difficult to reach a conclusion. The fact that the smelting company has admitted doing such damage in the past and has made monetary settlements therefor complicates the matter, since witnesses Nos. 8, 9, and 12 all received money from the smelter for horse losses and, therefore, their claim that these horses were affected similarly to those whose deaths were paid for carries weight. The fact is that no claim of injury or damage to horses within the past two years is made in these statements, but it is made in two instances as regards 1910, and in two instances as regards 1909.

INJURY TO VINEYARDS AND ORCHARDS.

In the course of this investigation it was not possible to find or learn of any case of typical sulphur dioxide damage to vegetation. I examined superficially a number of orchards and vineyards, but could find nothing resembling typical smelter burn. There is a great deal of claim and talk of damage to orchards and lands, but inquiry fails to sustain any such claim. Not a single person interviewed

claims to have noted the alleged damage at any particular period of time. The damage is claimed to be invisible and cumulative, and to be observable only after a period of months or even years. The smoke has never been known, so far as I was able to ascertain, to come down at any one time and to have burned any orchard or tree. This fact in itself should be reasonably conclusive on the question of alleged smelter damage to trees and orchards. It is so opposed to the characteristic damage from sulphur smoke elsewhere that it is impossible to believe that the injury complained of is due to the operation of the Selby plant. It might be possible to have cumulative damage if the sulphurous acid gas were constantly present for a greater or lesser period of time, or else be present at frequent intervals over a longer period in small quantities until the resistance of plant or tree to such influence was overcome. If this were the case, one would naturally expect to find a general complaint of greater injury to one class of trees than others, since the resistance powers of all would not be equal, but nothing of the sort is found. Furthermore, such a supposition premises that the smoke would be constantly present, in which case there would undoubtedly be complaint of continuing annoyance, which is contrary to the facts. There is one thing further against such a supposition, and that is so far as known no case of invisible economic damage from sulphurous acid gas has ever been established.

One thing stands out prominently in this claim of smelter damage to orchards, and that is the number who claim damage in 1910 but not since. Witnesses Nos. 5, 8, 11, 12, 26, 27, and 28 all claim to have had fruit trees or orchards injured in that year. As indicating the general nature of this condition, it may be stated that of those living in Benicia witnesses Nos. 45, 46, and 47 claim to have had orchard growth "killed" at that time. From the statements of the witnesses it would seem more like a blight of some sort than a smelter burn. Witness No. 48 also had trouble in that year, while witness No. 49 "had some splendid shade trees injured"; "the trees seemed to die out, the leaves wither and drop, and the shoots dry out;" "the damage was observable on the westerly side and top of the tree first, and the trees just seemed to die out gradually." No similar damage was observed before or since. As far as could be learned, this damage was not done at any one time, but was a matter of progressive development and was a general condition which manifested itself during that year. It seems rather peculiar if it were smelter damage that it should have occurred only during that year and not before or since, particularly when the volume of sulphurous acid gas has not been lessened. It would be expected to find the condition recurrent over a period of years if due to smelter operations. Witnesses

8, 11, 12, 27, 28, and 48 all say that their orchards are doing all right since. Witness No. 27 does not claim the loss of his orchard was due to the smelter.

The following are the particular cases of present damage alleged:

Witness No. 1 has a small orchard by the house, that he claims is being killed by the smelter. It has been set out for several years, but is not bearing fruit and looks poorly. He also has an eucalyptus grove that he believes the smelter is affecting. One side of this grove had been burned by a grass fire, but the trees looked as well as could be expected considering the drought. No evidence of sulphur dioxide burn was observed. It is interesting to note that witness No. 25, only a few rods farther up the road, claims no damage to trees or vineyard, the smoke not troubling those residing on the other side of the road.

Witness No. 5 has an almond orchard of five years' growth that he believes is slowly being killed by the smelter. This orchard sets on an exposed hillside, where it gets the full sweep of the cool winds and salt air from the bay. No particular damage is alleged save that the trees are doing poorly, in spite of what he considers careful cultivation. He also has a row of cypress trees by the house, set out about 40 years ago, that have commenced to die within the last year or two, a condition that he attributes to the smelter.

Witnesses Nos. 4 and 14 both claim that their orchards have been killed by the smelter, the trees dying after several years. Both orchards appear neglected.

Witnesses Nos. 16, 18, 20, 22, 24, and 26 all believe the smelter is injuriously affecting fruit trees and vines. Witness No. 16 claims, as proof of smelter damage, that trees set out four or five years ago do not have any greater growth than trees two or three years old. Witness No. 22 claims that foliage is less and that fruit does not mature, does not "develop the way it should," and the "way it does elsewhere." Witness No. 18 claims that each year up to this year after the vines had blossomed something in the air seemed to affect them so that the grapes did not form. Both witnesses Nos. 16 and 18 claim that this is the best year for fruit they have had for a long time in spite of the lack of rain. The latter also claims the smelter smoke has interfered with vine graftings, causing the loss of $1,000 worth of graftings which did not take owing to the smoke. Witness No. 24 has a vineyard about 10 years old that has died because of the smoke, and an orchard that is being killed. He states the trees begin to die out on the side toward the smelter and on the top, while the other side remains green. They do this year after year for a few years until the orchard is ruined. He pointed to the sparse foliage at the top of the trees as evidence of smelter damage.

Witnesses Nos. 8, 11, 12, 27, 28, and 49 all make no complaint of present conditions; in fact, all say their orchards, vines, or trees are doing all right now.

The question of smut on the trees, of which a number of these persons complain, will be taken up separately. From this brief résumé it will be observed that the complaints of damage all relate to general conditions, the growth of the trees, the development of the fruit, or the dying of the trees extending over a period of months and even years.

CONCLUSION AS TO INJURY TO TREES.

There is absolutely no evidence indicating that the smelter smoke has had an injurious effect upon orchards and trees on these ranches during the present year. There is no evidence indicating that it has injuriously affected trees at any time in the past. None of the injury complained of seems typical.

INJURY TO CROPS AND LANDS.

No instance of characteristic sulphur dioxide damage to crops of any kind was either observed or learned of. No person claims that any crop was at any time burned by the smoke from the smelter. The only claim in that respect is that lands exposed to the winds from the smelter do not raise as good crops as lands not similarly exposed. In this connection it is claimed in several instances that lands on the same ranch not exposed to the fumes produce an average crop while lands that are exposed yield only half as much. The feeling is that the land has been "poisoned" by the lead emanations, so that it can not produce as it should. This feeling is the outgrowth of the damage to horses that occurred in the past, the reasoning being that if the smelter was responsible for the deposits of lead and arsenic that brought about the death of the horses, then such deposits accumulating over a period of years would be equally injurious to all plant life and growth. A number of the farmers mentioned this "poisoning" of the land, but, strange to say, it was mentioned to me more frequently in Benicia than by the farmers themselves.

While this claim is unreasonable on its face, still the prevalence of the opinion requires that it be given consideration. The remark is frequently made in Benicia that years ago the country around Benicia used to produce the finest fruits and the largest grain crops that were grown in the State, but that since the smelter started running, the lands no longer produced as they should. This condition is attributed entirely to the smelter, ignoring the fact that the lands have been farmed continuously for a great many years without, in many instances, the use of fertilizers and without deep plowing, and that a light top soil is found throughout the region with a "hard pan" underneath, making retention of moisture difficult.

Witnesses Nos. 4, 9, 12, 16, 17, 18, 20, and 24 claim this condition exists, although witness No. 12 mentioned it only casually, while the others make a point of it. On the other hand, witnesses Nos. 1, 5, 8, 11, 19, 21, 25, 27, 28, and 29 make no mention of any such effect. Witness No. 10, who lives just below witness No. 9, declares that given water he can raise any kind of a crop without difficulty, and witness No. 21, who lives out by witness No. 16, makes the same declaration. It seems peculiar that some lands should be affected and not others, when the lands are similarly exposed.

OCCURRENCE OF SMUT.

There is one condition that has formed a subject of general complaint, and that is the presence of a black soot or smut, which spreads over the fields, blackening crops and stubble and also blackening fruit trees and fruit. Because of the fact that it was so noticeable, the presence of this substance has led to many of the claims of damage to orchards and lands.

The same thing that was remarked upon in connection with the discussion as to the relative amount of nuisance created by smelter smoke and oil fumes, namely, the improvement which seems to have been noted subsequent to the capping of the oil stills, is noticeable with respect to this smut. This smut, according to the testimony, was worse in the period prior to 1910 than it has been since. There seems to be no difference of opinion upon that point. It is not as noticeable either in the fields or on the trees, although it is still present to some extent. Witnesses Nos. 5, 8, 16, 18, 20, 22, 24, 26, and 28 all claimed to have noticed it this year, although to a much less degree. Witness No. 16 declared the smut was not 25 per cent of what it used to be, while the others declared it was "quite a little" less in the last couple of years. Witnesses Nos. 1, 9, 10, 11, 19, 21, 25, and 27 make no mention of it whatsoever, while witnesses Nos. 12, 13, and 30 claimed not to have observed any this year.

This smut, as near as I could get the various persons interviewed to describe it, seems to be slightly greasy in character; that is, it is not a dry, powdery substance, but something more sticky that clings to whatever it alights upon and does not brush or rub off. It was not a mold and did not seem to be an earth dust. Evidence of this smut was found on the ranches of witnesses Nos. 16 and 24, where it was particularly looked for. This smut is believed to be a lead deposit by witnesses Nos. 12, 16, 22, 24, and others. This belief on the part of witness No. 16 is based on the fact that a leaf bearing this deposit makes a "black mark resembling that made by a lead pencil." Witness No. 22 says it is sort of "grayish, like lead." I was unable to learn that this smut had had any injurious effect aside from darkening fruit, hay, etc., and interfering with the sale thereof.

It impressed me forcibly that so long as this substance is observed and so long as these ranchers have no reason to assume that it is due to any other agency or cause than the smelter, they will always consider the smelter is doing damage, the presence of this substance being tangible evidence that the fumes are carrying that far, from which it follows that the poisonous components of such fumes would also be carried over their lands; that is, the psychology of this situation renders it desirable to have some effort made to ascertain just what this substance consists of and the source whence it comes. There is nothing emitted by the smelter that could produce such an effect.

CONCLUSION AS TO DAMAGE TO LANDS AND CROPS.

From my interviews there is nothing, in my judgment, upon which to base a finding that the Selby smelter has been doing damage to lands or crops, either now or in the past. The region has suffered from three dry years, so there has not been very much of a crop of any kind, as a result of which the farmers have not had so much opportunity to dispose of their crops in the market, so that little or no evidence is available as to whether the smelter depreciates the price of crops. The prejudice that existed against hay on account of the presence of "lead deposits" seems largely to have disappeared, although it is said to still persist to some extent, both in the local markets and in the city market. Witness No. 1 was the only man who complained of this condition at present, but his complaint plainly related to previous years, since he has had to buy hay for his cattle in the last couple of years. Witnesses Nos. 12 and 25 mentioned it with reference to several years ago, but the others made no complaint on this score. The "lead deposit" which is alleged to have caused damage to horses in the past, does not appear to have injured vegetation. The only effect produced by it was to curtail the market for crops or else cause a slightly lower price to be given. The peculiar thing in this connection is that farmers claim that horses kept inside and fed this same hay were not affected. It was only the horses left out on the range that grazed when the heavy morning dews were present that were affected.

INTERVIEWS WITH RESIDENTS OF BENICIA.

These interviews were had in the early part of September of this year (1913), so that the expressions of opinion relate only to conditions up to that time.

Before discussing the evidence, it seems advisable to consider somewhat at length certain features as I encountered them, which have a direct bearing upon the evidence and the weight to be accorded same.

In the first place the majority of those interviewed manifested a certain restraint in discussing the smelter and its operations, which is plainly to be observed in the transcript of testimony. The caution and reserve thus manifested account in part for the somewhat equivocal characterization and description of conditions or improvements therein.

This attitude is the natural outcome of the situation that has been developed in Benicia. For approximately 10 years a more or less active agitation has been going on against the Selby smelter. The agitation began with the farmers who have been the most bitter complainants all along, and who aroused the sympathies of the citizens with their declarations of inability to raise crops or to keep horses. The frequency with which horses died, some of them on the main business street of the town, together with the distressing blowing or roaring that was characteristic, did more to arouse the community to action than any other one factor.

During these 10 years all sorts of rumors and statements have circulated as to the effect of the smelter smoke on lands and vegetation, animals, and human beings. These statements and claims have been so persistent that many are inclined to believe the smelter capable of most any form of injury. Some people, because of the extent of the agitation, attributed all kinds of ailments to the smoke, and complained, and complained bitterly, when others could not notice or perceive anything in the air. This has led to the belief that some persons can notice the fumes and are affected by them when others are not, and naturally there is a hesitancy when some complaint still exists to assert that the smoke is wholly absent when others complain, and this leaves some degree of doubt in the minds of many as to the improvement effected.

Again, there is a quite general feeling that although an injunction against the operation of the smelter has been in effect for five years, yet the smelting company with unlimited means at its command has been able to fight off the enforcement of it until now, and that the community is waging a hopeless fight against a rich and powerful corporation. It is felt that the commission is only an agency of the smelter to aid it in procuring a modification or removal of the injunction. With this injunction out of the way, it is felt that the smelter would be at liberty to operate as it pleased, and conditions would soon be as bad as before. Naturally, then, there is some resentment at this, and a feeling that whatever advantage or control is now had over the smelter must be retained, which colors opinions or statements as to conditions.

Again, the smelting company has had several agents in Benicia who have gone about asserting that the alleged smelter smoke was in

reality oil fumes. They made sufficient converts to stir up quite a bitter controversy on the subject, and have succeeded in confusing many people, so that many of them say they are unable to tell whether it is oil fumes or smelter smoke that bothers them. These agents tried to conceal their connection with the smelter, won the confidence of various persons, and gained expressions of opinion which subsequently were used against them. This has led to a suspicion of every stranger who goes around seeking information, and has begot a natural caution in spite of the apparent bona fides of the mission, which manifests itself in the evidence. Furthermore, some of the residents have been so bitter against the smelter that those who have not been particularly annoyed hestitate to take issue with them, and are led to qualify their statements or views as a result.

The combination of these factors is responsible for this general attitude, which was observed and remarked upon in the beginning, and helps to throw some light upon the evidence.

SMELTER SMOKE, DUST, FUME, AND GASES.

The same inability to furnish data as to the frequency of the smoke that had been encountered among the ranchers was found to exist in Benicia itself. A few persons only had kept notes of the times when the smoke had been observed, but not one of these persons had noticed the smoke more than four times. Witnesses Nos. 40 and 41 had noted the smoke four times, witness No. 50 three times, and witnesses Nos. 51 and 52 two times.

No one could go about and listen to the testimony of these varied witnesses and receive any idea or impression that conditions were bad or had been bad during this year, or that the smelter constituted a public nuisance. The manner in which it was asserted that conditions are "nothing like as bad," "not bad," etc., would clearly convey the impression that the witness did not consider that conditions were at all bad, or gave ground for complaint. At the same time this variance in the modes of expressing the opinions of the witnesses regarding present conditions makes it difficult to work up a statistical analysis of the evidence on this point.

My firm conviction is that no fair-minded person in the city proper considers that the smelter has been a nuisance during the present year. The general feeling among business men and others whom I interviewed was that conditions were all right now, if the smelter continued to be operated as it had been during this year. There seemed to be a lively dread, however, that conditions might become worse if the commission reported that the smelter was not violating the injunction, and the smelting company succeeded by reason of such report, or by any other means, in having the injunction removed or substantially modified. There are a few who are not willing to say

that the smelter is not a nuisance now, and who consider that the smelter is a nuisance at such times as the smoke comes, but these persons do not state that the smoke has come with anything like sufficient frequency to constitute a nuisance within the meaning of the decree and judgment.

I believe the following expressions of opinion fairly represent the general feeling of fair-minded persons.

Witness No. 40 says:

If the smelter continues to operate as it has operated in the past seven or eight months, there can be no reason to complain on the part of the people of Benicia. For my part, I don't believe there is a man, woman, or child in Benicia who, if they told the truth, would not have to admit that it (the smelter smoke) was not anything like it used to be. Not anything like. No one can say anything different.

Witness No. 41 says:

The smelter has given us practically no trouble this year. I don't think anybody has any ground for complaint the way things are now.

Witness No. 53 states:

I don't think any fair-minded person could enter any serious objection to conditions as they have existed in the last seven or eight months.

Witness No. 54 says:

If the smelter keeps things no worse than they are now, it is not so bad.

Witness No. 55 says:

We still get the fumes when the wind is right, but nothing like we used to get them. I have not heard much complaint on any side lately. A fellow ought to be able to put up with a little inconvenience anyhow.

Witness No. 56 says:

There is no serious cause of complaint, so far as I am concerned, with the sulphur fumes; in the last two or three years they have not bothered me any.

Witness No. 57 says:

The fumes are reduced in quantity to such an extent that I do not notice them unless I pay particular attention. * * * I have not noticed them very much this year. * * * It is not as noticeable as it has been in the past. In the last three or four years there has been a noticeable improvement.

Witness No. 58 says:

I have not smelled it at all for the last two or three years. If a man is to be honest and frank, he must admit it has been eliminated. * * * No one can complain the way things are now.

Witness No. 59 says:

People are willing to suffer this little that they are getting now, but the majority of them are afraid that after the commission is dissolved the smelter will try and have the injunction removed, and then will proceed to give us the same old dose again, which would mean the spending of thousands of dollars again to fight them. * * * If Selby continues to operate the way it is now, and there was no way to come back at us, people would not kick.

Witness No. 60 says:

I don't think there is any doubt but that there has been a great change. In fact I am satisfied with conditions the way they are now, without waiting for the recommendation, report, or finding of the commission. If they do no worse than at present we should have no reason for complaint.

Witness No. 61 says:

If conditions get no worse than they are now, then I am entirely satisfied. If we get it a day or two, what harm does it do? I am perfectly satisfied with conditions as they are now, if they do not get any worse.

These opinions might be multiplied, but I consider that they represent the views held by the greater portion of the citizenship of the community. The men whose opinions are given are representative citizens, including prominent city officials and business men. Of course, all the opinions are not expressed as emphatically, but, regardless of phraseology, the greater portion of those interviewed do describe conditions in such a way as to make it seem evident that their conclusions do not greatly differ. In fact, so far as the main part of Benicia is concerned, the testimony ran so uniform that I was thoroughly satisfied that the smelter does not now constitute a nuisance. While there were exceptions, of course, yet the great weight of the testimony supports this conclusion. It seemed to me that further testimony in the town itself would be purely cumulative, and would not lead to any other conclusion than would be reached with the evidence at hand. While this was true as to the main section of the town, I did find considerable complaint of trouble from the smoke in the section of the city out along by the shipyard, and from there on in to the old bridge by McKay's tannery. The houses here are directly along the water front where they get the full sweep from the straits.

An analysis of the testimony of 135 citizens of Benicia furnishes the following results, with respect to conditions this year (1913):

2 persons have not noticed the smoke at all.
10 persons have not noticed the smoke in two to four years.
6 persons have not noticed the smoke the last year or so.
13 persons have not noticed the smoke this year.
7 persons have not noticed the smoke for past five or six months (practically this year).

38 persons have not noticed the smoke this year.

20 persons have noticed the smoke not more than four times this year.
60 persons state the smoke is "not as bad," "not very much," "not near as bad," "very little," etc., or has not been noticed only "a few times," "several times."
6 think conditions are just as bad as ever or are still very bad.
3 get the smoke from once or twice a month to once or twice a week.
5 get the smoke "quite frequently," "quite a number of times," etc.
3 refuse to make any statement whatsoever.

Expressed in another way, 29 per cent have not noticed any smoke this year; 15 per cent have noted it less than four times,

while 44 per cent find conditions "not nearly as bad," etc.; 88 per cent accordingly have either not noted the smoke at all, or have observed it not more than four times, or find that present conditions are "not nearly as bad," etc. Only seven persons, or 5 per cent, claim that conditions are as bad as ever, while eight persons, or not quite 6 per cent, claim to get the smoke rather frequently.

As stated previously, there seemed to be more general complaint of the smoke this year, as well as in past years, in the exposed stretch of road from the cove by Carty's up to the Gould place, where the road makes a sharp turn from K Street into J Street, than elsewhere. Some twenty families live along here.

Of these families, witnesses Nos. 45 and 68 are the only ones claiming not to have noticed the smoke this year; witnesses Nos. 48, 69, 70, and 71 have noticed it only a very few times—two or three, witness No. 69 claims; witnesses Nos. 67, 72, 73, and 74 claim to get it once in a while. Witnesses Nos. 46, 64, 65, 66, 75, 79, and 80 claim that conditions are as bad as ever and that the smoke comes with great frequency; witnesses Nos. 76, 77, 78, and 14, all claim to have had it a number of times, the times not being specified.

Of these people, witnesses Nos. 14, 46, 64, 65, 66, 75, and 79 are the only ones apparently who claim that the conditions are bad. Of these families, it appeared to me that the testimony of witnesses Nos. 45, 48, 67, 68, 69, 70, 71, 72, 74, 81, and 82 gave the fairest view of present conditions, and I believe any conclusions based on their combined testimony is the correct one. It is not possible to judge of the strength of the smoke, since some people seem to be much more sensitive to it than others and since the witnesses could not be made to express a positive opinion.

Of these 20 families, 11 have not noticed the smoke at all, or only "a few times" or "once in awhile"; 5 claim that the conditions are "as bad as ever" and that the smoke comes with great frequency; and 4 claim to have had the smoke "quite a number of times."

There is a greater variance of opinion in this small section than elsewhere in Benicia, but, taking into consideration all the evidence and the impressions created by the various witnesses, I believe that while they may have had the smoke a few more times than in Benicia proper, it has not been a general nuisance, or been so severe or continuous as to interfere with the comfortable enjoyment of life and property. That is my personal conviction, notwithstanding the more apparently numerous bitter complaints. Witness No. 14 exhibited deep resentment against the smelter, but this was clearly inspired by conditions in years past; witnesses Nos. 46, 64, and 77 are all ailing women, and their physical condition seems to have influenced their views and judgment. The statements of witnesses Nos. 65, 66, and 75 seemed exaggerated to me, and are opposed to the testimony of their neighbor, witness No. 67, and the statements

of their employer, witness No. 81, and that of other workmen at the same place. The statement of witness No. 79, in my judgment, is not dependable, and is contradicted by that of his immediate neighbors, witnesses Nos. 68 and 82, while the statements of witnesses Nos. 73 and 76 are not consistent.

DATES WHEN SMOKE WAS OBSERVED.

The only dates that were given to me as those upon which the smoke had been observed follow:

Dates on which smoke was observed.

Date.	Time of day.	Observer.
1913.		
May 23	Forenoon	Witness No. 50.
June 15	Afternoon	Do.
June 19	Early morning	Do.
July 5	Midday	Witnesses No. 51 and 52.
August 4 or 5		Witness No. 83.
August 18 or 19		Witness No. 15.
August 23		Witness No. 8A.
August 25		Witness No. 12A.
August 28	No time of day specified	Witness No. 84.
August 29	Night	Witness No. 85.
Do	Forenoon	Witnesses Nos. 84, 59, 40, 51, and 52.
August 30 or 31		Witness No. 26.
September 3		Witnesses Nos. 64, 66, and 88.
September 2 or 3		Witness No. 22.
September 4		Witnesses No. 75 and 65.
September 5		Witness No. 89.
September 6		Witnesses Nos. 90 and 91.

Incomplete as the above list of dates is, it shows some interesting comparisons. Witness No. 50 and witnesses Nos. 51 and 52 claim to be very sensitive to the smelter smoke, yet the former has three dates on which he was troubled with the smoke and they were not, while the latter were troubled on two days that he was not. Witness No. 85, who occupied a room at the Anderson house, claimed to have been awakened during the night of the 29th of August by the smelter smoke, which caused him to cough for fifteen minutes or more. I did not smell anything, or suffer any annoyance, although I had a room with a like exposure. This witness is the only one who mentioned this to me, and he and his wife were the only ones in the house to be so affected. Witness No. 84 claims to have noticed it on August 28, but none of the other men on board the ferry steamer mentioned it as being present on that date, nor did witness No. 92 with whom he boards. August 29, several persons mentioned having observed the smoke, namely, witnesses Nos. 40, 51, 52, and 59, but with three exceptions these are the only persons who made mention of having observed the smoke on that date, although I saw most of the people in the town subsequent to that date. The three exceptions are persons who claimed at the time of the interview to have noted the smoke the previous week, but could not name the day or date,

but did say it was the latter part of the week, so that it is assumed they did notice the smoke on this date.

Witnesses Nos. 12A and 15 live across the road from each other, yet the former noted the smoke on August 18 or 19 but not subsequently, while the latter noted it on August 25 for the first time in a month. On the other hand, witness No. 8A noted it on August 23 for the first time in a year, but her nearby neighbors whom I saw did not make any mention of the smoke being present at that time, although I interviewed them only two or three days subsequent thereto.

Again, witnesses Nos. 22 and 26 are neighbors, their places adjoining; the latter noted the smoke on August 30 or 31, while his neighbor did not; witness No. 22, on the other hand, noted the smoke on September 2 or 3, while his neighbor did not.

Witnesses Nos. 65 and 75 claim that the smoke was present on September 3 or 4. I interviewed every one along that road on the 5th, yet with the exception of witness No. 64 no one claimed to have noticed the smoke on those days, which it is reasonable to suppose they would speak of if observed, owing to the recent prevalence of the smoke. Witness No. 64 claimed to have noticed the smoke on the 3d but not on the 4th.

PERSONAL OBSERVATIONS.

On the 28th and 29th of August, when the smoke was claimed to be present, I was out among the ranches and was unable to perceive any trace of sulphurous acid gas in the air. On September 3, the date on which witnesses Nos. 22, 64, 65, and 75 claimed to have noticed the smelter smoke, I was in Benicia and was absolutely unable to perceive anything. While interviewing witness No. 88 at the Kullman-Salz tannery on that date, he declared that "the air was pretty heavy with smelter fumes." It was imperceptible to me, and also to two other of the workmen to whom I spoke. On September 5, while interviewing witness No. 89, she declared "the smelter is giving it to us heavy to-day." I did my best to detect a trace of sulphur dioxide, but could not. The following day, while at the Anderson for lunch, witnesses Nos. 93 and 94 informed me that the smoke was present, and very noticeable. I walked down to the water's edge in direct line with the smelter, and could not see smoke coming up the straits, nor could I obtain any trace of it.

During my stay in the region, I noticed the smoke on just two occasions; once while driving along below the shipyard toward Benicia I caught a faint trace of it, but was unable to get another whiff, although I drove for a quarter of a mile in either direction in the endeavor. This was on August 26, when no one claims to have observed the smoke. The other occasion was with Mr. Gould and Dr.

Franklin, of the commission, when with a high wind blowing we caught a faint trace of sulphur dioxide. While I was at the ranch of witness No. 16 he claimed that there was a slight sulphur odor in the air. It was too slight for me to notice. Mr. Wells and I were at witness No. 78's place on September 30, at which time the witness claimed to detect "sulphur fumes." Wells and I did our best to detect sulphur dioxide, but without success.

These experiences of my own confirm what many of the residents of Benicia told me, namely, that frequently other people would remark that the smelter was bad when they could not observe a thing. The great diversity of dates shown, with the fact that only one or a relatively few persons observed them on the particular dates, and the further fact that one person in a neighborhood notices them while another or others do not, leads to the conclusion either that the sulphur gases are so diffused by the time they drift the 5 miles from the smelter that only faint traces can be had now and then, which one person might observe and another would not, or else it is imaginary. If what was imperceptible to me is called a "strong" or "heavy" fume, as it was by witnesses Nos. 88 and 89, then it does not appear to me that the smelter can be much of a nuisance. It should be kept in mind that no one claims now that the smoke is present for hours, the way it was years ago. My own conclusion is that small quantities of sulphur gases, sort of stray whiffs, can still be noticed at times, which would account for individual as distinct from general complaint. This conclusion is supported by the fact that there does not seem to have been any one day or part thereof on which the smoke was so bad as to give general complaint.

I have observed the smoke from the Selby stack drifting down from the top of the stack and going up the straits, but I have never seen it travel for any great distance during the limited time I was in the region. There seems to be a characteristic haze observable along the shores and back toward the hills on both sides of the straits, which is added to by the volume of smoke from trains, boats, and from other plants along the shores. Sometimes this is light bluish in character. Unquestionably this is considered to be smelter smoke at times. For example, on August 26 witnesses Nos. 15 and 95 pointed out this condition that I term "haze" and observed that it was smelter smoke. Witnesses Nos. 11 and 12A declared it was not smelter smoke, which I knew to be the case, as I had just driven over from Dillons Point and had seen the smelter smoke driving back along the Contra Costa shore. Quite a few times this condition in the straits was pointed out to me as smelter smoke when it could be seen drifting over the White ranch or over the tules beyond. Looking over on the Contra Costa shore the same condition could be observed, and the haze seemed as dense on the one shore as the other.

PSYCHOLOGICAL ASPECTS OF CONTROVERSY.

These and other experiences, as well as observations in general, have served to convince me that the question of the Selby smelter smoke at present is to a large extent a psychological one. It is my firm belief that so long as a certain class of the residents of the district know that the smelter is operating, and so long as they have ocular evidence that smoke or gases are coming from the smelter, they will continue to believe that cause for complaint exists. I believe that I am normally sensitive to sulphur dioxide, but when persons can observe it when it is imperceptible to me and to others, it must be believed either that they have superior powers of observation, in other words, are supersensitive to the fumes, or else are suffering from an honest but nevertheless mistaken belief. So long as occasionally they perceive smoke coming from the smelter stacks, they will believe that haze or fog contains smelter smoke or is smelter smoke, and will continue to find annoyance or damage. Every condition out of the ordinary, for which no explanation can be given within the limits of their experience, will be attributed to the smelter. Perhaps as good examples of this as any are the following cases:

Witness No. 96, a dock laborer in the employ of the Southern Pacific Co., and a man who has done the hardest kind of work for years, has had, for seven or eight years, some kind of stomach trouble of such a severe character that he has been unable to keep food on his stomach. He has doctored for years without relief, and has been told it is due to ulceration of the stomach. Notwithstanding this, he is firmly convinced the smelter alone is responsible.

Witness No. 46, a sickly, anemic woman, has been ailing for years. The doctors have pronounced her ailment different things, but she "knows" it is simply the smelter that is responsible.

Witness No. 97 has "one lung entirely gone," as it is termed, due to tuberculosis. She has a distressing cough in the mornings and finds it difficult to breath in the early morning air. This is due to the smelter, and her husband is so distraught with her illness that he can see clouds of sulphur smoke rolling up the straits every morning (see testimony).

Witness No. 98 lost a cow and calf this summer. She was not sure whether it was the smelter that killed the cow or not, but she did know "the smelter smelled awful bad" the night the cow died.

Witness No. 99 has developed a little throat trouble in the last two years, for which he blames the smelter, notwithstanding the fact that he has found the smoke much less in that time, in fact, has not noticed it very much at all.

Witness No. 100 has two little girls who have had quite a little throat trouble of late. He does not know whether to blame the

smelter or not. Still he has the idea that the smelter might be responsible.

Witness No. 77 has a white mold on her plants which she is inclined to think is due to the smelter. If there is anything in the world that sulphurous acid gas would not cause, it is mold.

Witness No. 92 has had trouble with her roses, the leaves seeming to turn black in a day, not covered with a black deposit, but turning black over night. This, she is told, is due to the smelter.

Witness No. 22 has been living at his present place of abode for three years. He finds that the trees do not have as much foliage as elsewhere, and that the fruit does not attain the same perfection. These three years have been dry years, little or no rainfall in that region, yet the smelter is responsible.

Witness No. 64 was sick about a year ago; she did not know what was the matter with her, but her physician said it was the "smelter."

Witness No. 87, in the rolling room at the tannery, where a considerable amount of fine dust is given off from the tanned hides, had eye trouble several years back. His physician also told him this condition was due to the "smelter."

These are not all the cases by any means, but they are sufficient to illustrate what is meant when it is said that the question is to a great extent a psychological one. So long as visible smoke is permitted to be discharged from the stacks, a great many people are going to continue to believe that harm is being done—if not visible harm or damage, then some insidious form of damage that will manifest itself after awhile. There is no question in my mind but that there are people who, because they know the smelter is still discharging visible smoke, feel that they must smell it at times. In the same way some of those who are ranching, so long as they are aware that smoke is coming from the stack at the Selby plant, will continue to feel that damage must still be done, and inexplicable conditions, such as the failure of vine graftings to take, decreasing yield from fields, the failure of sheep to multiply as they should, the failure of mares to foal, etc., will be laid at the door of the smelter. Convictions of this character, which are the result of years of agitation, of the circulation of all kinds of baseless rumors of harm and injury, are extremely difficult to change.

RESUMÉ AND CONCLUSIONS.

SMOKE IN 1913.

There seems to be no doubt but that the smelter smoke has been observed in Benicia this year (1913), but only a very few times, not exceeding a half dozen in number, according to the great majority of those interviewed, and these at varying dates and times. The smoke when present does not seem to have been generally observed,

some noticing it and others not. This leads to the conclusion previously expressed that the sulphurous acid gas is so diffused when it reaches the main part of the city that it is not strongly noticeable, and is observed only for a very limited period. Those who are affected with throat troubles seem to find a whiff of the sulphurous acid gas to be very irritating, though it might not be observable by others. It seems, also, that the smoke is so diffused that its presence is detected more by this irritation than by the sense of smell. Even out along the road by the shipyard it does not appear that the smoke is noticed at the same time by all who live along there, nor do the reports of the effects produced coincide, some claiming to be very much distressed, while others are not bothered particularly.

I was able to find no evidence of any particular day when people generally were affected, although it would naturally be expected to find such evidence if the smoke was very strong. Again, if the smoke came as often as alleged along by the shipyard and was as strong as claimed by witnesses Nos. 65 and 66, for example, one would naturally expect to find that the smoke had carried back to the ranches beyond, but there does not seem to be any evidence of this sort. I do believe, however, that they have had traces of the sulphurous acid gas more frequently in that section than in the city proper.

CONCLUSION.

Taking the evidence as a whole, and as stated in the beginning, I can not conclude that the smelter smoke, fumes, or gases have been such as to constitute a public nuisance so far as the city of Benicia is concerned, during this present year, and can not believe that anyone could reasonably find otherwise.

SMOKE IN 1912.

With respect to conditions in 1912, the testimony is not quite so consistent. There appears to be a greater difference of opinion with respect to conditions in that year. Out of 122 people, 17 comment on the fact that this year is better than last year, while the great majority of those who find an improvement in conditions link the last couple of years together in speaking of such conditions. It was as difficult to get any data with respect to the frequency with which the smoke had come in 1912 as it was for this year. This was to be expected, as if people could not remember how many times they had had the smoke this year, they would hardly be able to recall how often they had had it in previous years. The best that could be done was to get an expression of opinion couched in general terms.

An analysis of the testimony of 122 persons gives the following results:

6 persons did not remember what conditions were.
22 persons did not notice the smoke during that year, or for a year or more prior thereto, or were not "bothered."
60 persons found the smoke "not as bad," "not as much," "not bad," "much better," "very little," etc.
16 persons described conditions as better than previous years, but as still affording cause for complaint.
18 persons found conditions just as bad as ever, or still bad, etc.

Expressed in percentages, 16 per cent found conditions just as bad as ever or "pretty bad." Thirteen per cent found conditions better than in any preceding year, but still not satisfactory. Eighteen per cent were not bothered or did not notice any smoke at all, while 49 per cent found the smoke "not bad," "not as bad," "not very much," etc. Four per cent did not recall whether 1912 was a bad year or not. The year could not have been a very bad one or these persons would have had some distinct recollection of that fact. Thus it may be said that 71 per cent did not notice the smoke at all or did not find conditions very bad.

I feel that figures such as these give a wholly unsatisfactory view of the situation that existed last year. Expressions like "not as bad," etc., when used as descriptive of conditions have to be read in connection with the rest of the testimony to get a correct line on what is actually meant thereby.

The only conclusion which can be reached would seem to be that the majority of persons did not find conditions on the whole to be bad. The majority of persons affirm that they have not been as bad in the last couple of years. While a number claim the smoke was bad during the year, they do not assert that it was bad continuously, or more than a few times. That there were "some" bad days last year, or that there were a "few" days when it was bad was the most that I could drag from anyone. It appears to me from this testimony that the conditions last year must have been very similar to conditions this year, and that occasional whiffs only were had at varying intervals, observed only in comparatively small areas. It was impossible to learn whether the day that one person claimed was bad last year was a subject of general complaint, since no records seem to have been kept on the subject any more than they were kept for the present year. I am thoroughly satisfied, both from my experiences and the conflicting statements, that many people in Benicia are inclined to call the smoke bad or term a day as bad when they can detect the slightest trace of sulphur dioxide, so that when it is said there were a number of bad days, it throws little or no light on the strength or duration of the smoke and the degree of offensiveness, if any, that would normally be caused.

The number who signed the petition in November, 1912, praying for the closing down of the smelter and the enforcement of the injunction, gives no reliable index of the sentiment of the community. Two hundred and forty-seven names are signed to the petition, of whom I interviewed some 70. In many instances the name of both husband and wife is affixed to the petition. When I had interviewed either one, it seemed necessary to interview the other, so that the number interviewed would amount to considerably more if the one could be considered as testifying for the other. The majority of these persons give testimony which is at variance with what would be expected of those signing such a petition, and confirm the belief that they signed merely because approached and asked to sign, rather than because they felt that conditions were so bad as to require it. I note the names of a number of persons who testified that they either did not notice the fumes at all, or else noticed them but very little, among such persons being: Witnesses Nos. 10, 30, 31, 43, 44, 45, 68, 69, 71, 88, 99, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, and 111.

CONCLUSION.

Viewing the evidence in all its phases, I can not find that there are sufficient grounds for concluding that the smelter smoke, fumes, or gases constituted a nuisance during the year 1912. That it caused some degree of annoyance at odd times to some of the residents must be accepted, but that it amounted to a genuine nuisance, interfering with the confortable enjoyment of life and property, is not established, and this notwithstanding the presentation of the petition.

SMELTER SMOKE AND OIL FUMES.

The evidence seems to bear out to some extent the contention of the smelting company to the effect that oil fumes contributed in part to the degree of nuisance that previously existed. The fact that most impresses one is the number of those who claim that the smoke was so oppressive in the nights and early morning up to two or three years ago. Out of 137 persons, 41, or a little less than one-third, complained of being awakened during the night or early morning by a stifling or choking odor that would arouse them from sleep and compel the closing down of the windows, or of being troubled with heavy, oppressive fumes in the early morning hours. These people have had little or no trouble of this nature in the past two or three years. This fume or gas that prevailed at that time seemed to furnish the cause of the most bitter complaint, and since the elimination of same, conditions are found to be greatly improved. Some of the more pertinent evidence along this line is set forth below.

Witness No. 112 claims that they do not get the fumes in the night now so much as during the day. Up to a couple of years ago

they used to get a "very heavy and oppressive odor" which would make his wife vomit. "The odor was something different from sulphur, altogether. Was a pungent sort of odor; would dry up the throat and nauseate you." When they began to move around the house in the morning they would find the house full of it. They have had very little of that lately, although his wife complained of being awakened out of her sleep one night this summer.

Witness No. 110 had a great deal of trouble up to three or four years ago. Was troubled worse in the morning with a "very disagreeable fume," which caused "a choking sensation," so that "if you coughed much it would make you throw up or something;" was not altogether "a sulphur fume;" what else was mixed with it he did not know. His son had to move out of town on account of it, but in the last two or three years has not been bothered at all.

Witness No. 99 has not been troubled "much" in the last two or three years. He used to be compelled to get up about 5 o'clock in the morning and close the windows on account of the fumes. "The effect was more of a sickly fume—more of a nauseous fume; would be so bad I would have to get up—would wake you up. The odor was not like that given off by an oil-burning locomotive when going through a tunnel. I do not see why they let loose something in the morning the way they have done. They seemed to shoot it to us in the morning. The morning is the only time it seemed to affect us to such a degree. The fumes do not seem to be sulphurous; seemed to be something different."

Witness No. 113, an old mining superintendent, a graduate of Freiburg, and formerly assistant superintendent of a large Montana smelter, gives some valuable testimony along this line. Three years ago he was awakened by a choking sensation, compelling him to get up and place a wet towel over his head in order to sleep. The odor was altogether different from any "sulphur or lead fume" he had ever noticed in or around any smelter, and seemed to him to be an odor given off in the refining of oil. If this odor had continued up to the present time he would not live in the town for a minute.

Witness No. 114, an experienced copper miner, stated that up to the last year or so they had a fume in the early morning that he could hardly stand, and that would have driven him out of town if it had continued since that time. This fume was altogether different from any "sulphurous fume" he had ever experienced in and around Butte. In his own words, "This smell that I got here (in Benicia) was a wholly different odor (from sulphur dioxide). I could not have stood this kind of a fume that we used to have here; could not stand it. It used to bother me a great deal; the whole room used to be full of the smell; would nearly suffocate me. The smell was something heavier, more oppressive, than sulphur fumes."

Witness No. 115 used to be troubled in the early morning with a nauseous fume, but finds that this has disappeared in the last two years, though occasionally he notices something in the air that causes irritation of the throat and a cough. "I must say that the fumes are not as bad as they used to be. The smell is nothing like it used to be. The smell has almost disappeared, but the irritating effect still remains * * *. It was a very oppressive odor and would even affect me in the stomach, it would come so strong. In the last two years I have not noticed this nauseous odor as much as before; it might be a little longer than that. I have not experienced the nauseous odor in a long time."

Witness No. 102 four and five years ago worked out on the ranches, and states that they used to be troubled in the early morning with a heavy choking odor that would make them tie handkerchiefs over their heads in order to breathe. In his rough language he describes it as follows: "Was a sort of a heavy rotten smell; a d——n strong stuff, whatever it is. We used to get the same smell around town two or three years back. I could not tell what smell it was. It was a rotten smell, whatever it was." He has not noticed this in the last two years.

Witness No. 116 complained of a fume several years ago. He says: "It seemed to be a very heavy odor; seemed to choke me up. A kind of a staggering rotten smell that I used to get in the morning."

These quotations seem sufficient to indicate that there was something else present in the atmosphere up to a period variously placed as from two to three years ago, which caused a great deal of annoyance and contributed materially to the nuisance which existed. In addition to these extracts, the testimony of witnesses Nos. 47, 53, 57, 68, 108, 109, 117, 118, 119, 120, 121, 122, and 123 throws further light on this condition and supports the above conclusion. The testimony of a number of others suggests the same conclusion, but is not as direct and explicit.

Two-thirds of those interviewed find conditions improved in the last two or three years and the nuisance lessened. My own conclusion from this testimony is that the fumes which were complained of at this time of day constituted the greater part of the nuisance alleged to exist. Those who complained of the fumes at other times in the day do not mention this stifling, choking feeling, and do not make the same bitter complaint as do those who speak of these night or early morning fumes.

The odor described and the effects produced are distinct and different from those attributable to smelter smoke. At the same time the coughing and irritation would seem to be due to sulphur dioxide, or at least to be characteristic of it. Many who spoke of this former prevailing condition complained both of the coughing and irritation as

well as the stifling, oppressive odor. The fact remains, however, that the so-called "smelter fumes" have not been as noticeable in the past two years and do not seem to have been as offensive.

Whether any oil fumes contribute at the present time to what complaint of smelter conditions still exists can not be determined to any satisfactory degree. Only 31 persons out of 137 claim to be able to detect the oil fumes, and of these only 2 describe the odor as that given off in the refining of oil. The others declare the oil smells observed resemble either the smell of crude oil, the smell of burning oil given off by a locomotive, or else is like that observed when going past the refinery at Oleum. A number are so confused by the controversy that has raged as to the difference between oil fumes and smelter smoke that they do not know whether what they occasionally smell is the one or the other.

It is peculiar that of those who complained of the heavy oppressive odors in the morning and who noticed the fumes at other times in the day all claim that the smell was always the same. It is just the same kind of a smell now, though with very few exceptions they declare it is not as strong a smell. In a number of cases I could see that the witness felt I was trying to trap him by asking such a question. I found that the residents appeared to resent the idea of the smelter making the oil works the scapegoat, and this may account to some extent for the invariable response that the fumes are the same in character.

Approximately a dozen of those who claimed to be able to identify the oil fumes claimed that a number of people mistook the oil fumes for smelter smoke, but in every instance they were unable to give me any idea of the frequency with which the oil fumes had come, although they declared without exception that the oil fumes were observable but seldom. This means that approximately 20 per cent of those interviewed do notice oil smells, but their identification of these smells is not sufficient to establish that the smells observed come from the Oleum plant. This leaves it a matter of doubt as to what extent, if any, the oil fumes from the Oleum refinery contribute to such nuisance as may exist. If the stills are capped, and the ill-smelling fumes complained of came from the emptying of these stills as contended by the smelting company, then, unless occasional trouble is experienced with the capped stills, the odors therefrom would contribute but little to the nuisance. If the oil fumes do still come, they either are not recognized, or, if recognized, are not correctly described.

It is not a fact, apparently, that the complaint was confined to the early morning hours, as 47 persons spoke of getting the fumes during other times of the day. Either the oil fumes or odors were given off fairly continuously throughout the day, and were hence noticed at other periods than the night and early morning, or, what seems more

plausible, the sulphurous acid gases were observed at other times and at varying intervals by some people. To what degree, if any, the oil refineries along the straits added or add to the volume of sulphur dioxide or trioxide given off by the smelter is something to be determined. It is possible that they have added, and are adding, to it, even though the offensive odor may have been successfully bottled up. The complaint that did exist, speaking generally, with respect to conditions during the night and early morning has been largely, if not entirely, eliminated, and the time of such improvement seems to be coincident with the time when the stills at the oil works were capped. This does not mean that all complaint has been eliminated. Eighteen people claim to have noticed "the fumes" in the early morning of this year, although only five of them claim that "the fumes" were as strong or the effect the same as heretofore. These five are witnesses Nos. 46, 63, 65, 66, and 75. Witness No. 98 claims that "the fumes" last year were as strong and as bad as ever. Three persons claimed to be troubled during the night or early morning last year, but were not so troubled this year. "The fumes" now when noticed appear at any time during the day, no particular time standing out prominently, which is what would be expected if the annoyance is due to smelter smoke.

CONCLUSION.

The conclusion can not be reached, in my judgment, that the oil fumes, if present as claimed by the Selby Company, constituted the whole nuisance alleged to exist. Complaint existed at other times than nights and early mornings and has continued since. Some people seem, or claim to be, as much affected at rare times as before, though for shorter lengths of time. The ground for complaint appears so much less since the elimination of such fumes, however, that it is assumable that the injunction proceedings would not have been started if conditions had been as they are now, or have been in the past two years, provided the smelter was not emitting any greater volumes of sulphurous acid gas than it has in these years. This leaves out of consideration the damage to horses, which was a large factor in the trouble.

INJURY TO TREES AND VEGETATION.

There seems on the whole to be little complaint of injury to trees and vegetation in the city among those I interviewed. I was unable to learn of any damage that sounded as if it might have been caused by the smelter smoke. In both driving and walking about town, I examined the trees along the streets and in the various yards, but I could find no trace of what looked like a sulphur-dioxide burn. The evidence of smelter damage was nonexistent so far as my investigation went.

It has already been mentioned that witnesses Nos. 45, 46, and 47 claim that their orchards were killed some three or four years ago. Witness No. 48 also claims to have had trouble at that time. This damage was not a sudden damage but a gradual one, observable after a period of time. The trees died out on the side toward the smelter first. These orchards have not thrived since that time, and the first three witnesses believe that the smelter is still injuriously affecting them. The former is not quite certain on that point, however. Witnesses Nos. 65, 66, and 75 (one family) have a small orchard, which is doing poorly, and which they are inclined to think is being affected by the smelter, though they do not positively assert that such is the case. Witness No. 64 has a few young trees set out, which she claims are being killed by the smelter smoke. Witnesses Nos. 76 and 76A claim that the smoke has injured trees on their place and has prevented the growth of garden truck. The trees would dry up and the leaves shrivel up and drop off. This trouble has been less this year. Witness No. 69 claims that he has been unable to keep any fruit trees on the place, that something seems to cause the leaves to shrivel up and drop off on the side toward the smelter and then in a year or two the whole tree has to be dug up. He has never noted the damage as occurring at any particular time and has never noticed any sulphur-dioxide burn. Witness No. 77 claims the existence of a white mold is due to the smelter smoke. Witnesses Nos. 72 and 72A claim that plants and garden truck will not grow owing to the smelter smoke, that the vegetables do not develop and mature as they should.

There are a few other claims of this character, which it does not seem necessary to set out in full. Enough have been enumerated to make it evident that the claims of damages are wholly distinct from the claims usually made of smelter-smoke damage. While this fact is evident enough, there does seem to be such a prevalent feeling that the smelter is responsible for conditions of this character that it is worth while to ascertain, if possible, to what the condition can be attributed. The other persons who make mention of this sort of damage are witness No. 118A, vegetables and flowers; witness No. 89, fruit trees; witness No. 124, cypress and fruit trees; witness No. 92, rosebushes; witness No. 79, fruit trees. These persons are the only ones who mentioned damage to trees or vegetation. The noticeable fact in connection with this is that all of these persons, with the exception of witnesses Nos. 118A and 124, live out along the exposed stretch of road commencing just beyond Burke's saloon, or else live directly on the water front. Witnesses Nos. 47, 89, and 92 live along the cove near McKay's tannery.

During the trial of the case resulting in the issuance of the injunction, no mention was made of damage to vegetation in the city, and

there can have been little of it or mention would be made of it by those who have been prominent in fighting the smelter. Witness No. 40, who has a beautiful place across the street from where witness No. 92 lives, with a yard full of shade trees and flowers, makes no mention of any damage whatsoever.

CONCLUSION.

There is no evidence whatsoever in my judgment of any damage to trees or vegetation due to smelter smoke, either during the present year or during past years. It is evident that there was some peculiar condition prevailing about three years ago that injured fruit trees, but the description of it does not resemble smelter damage in any way. That the smelter is not a nuisance in this respect is beyond question.

DAMAGE TO SCREENS AND WIRES.

There is quite a little complaint to the effect that the sulphur smoke eats screening of all kinds and wire fencing, netting, etc. It is said that sulphurous acid eats out wire netting, fencing, and screening, so that it lasts only a year or two years at the outside. It is claimed that screens on the side of the house toward the smelter are affected, while screens on the other side will last a great deal longer. Appproximately a dozen people mentioned this form of damage, but in spite of this fact I am satisfied that it is a general belief or complaint from what witnesses Nos. 41, 101, and 125 told me. Witness No. 126, a competent metallurgist, connected with the Benicia Iron Works, claims that this condition is due to the fact that there is so much salt moisture in the air and that he has heard people speak of this form of damage and has laughed at them.

CONCLUSION.

Knowing the destructive effect of salt moisture-laden air upon screens, etc., and observing conditions in the straits and the bay, where a strong tide runs and heavy winds whip the tops of the choppy waves, it would seem that this might account in a large measure for the damage complained of. It is worthy of note that at the time of the trial, examinations of screens, etc., in Berkeley showed higher percentages of sulphurous acid than did similar tests of screens in Benicia.

OCCURRENCE OF SMUT.

There is practically no mention of smut so far as Benicia proper is concerned. Witness No. 112 of the Port Costa Lumber Co. complains that the lumber in the yard is darkened by some substance that seems to grime into the wood. His wife also complained that flowers and vegetables were covered with a black smut, but stated that this condition has been much better in the past two years.

The above was the only mention of this substance in the main part of the city. Witnesses Nos. 57, 101, 127, and 128 spoke of observing the smut on the ranches up to several years ago, but since that time they had not observed any or been in a position to observe any. Coming to the long stretch of K Street by the shipyard, there is more mention of this condition. Witness No. 65 thinks the smut is just as bad as ever, though he has not been out in the fields to work this year. Witness No. 67 also complains of the smut on stubble, etc., but thinks it is less than in previous years. Witnesses Nos. 45 and 69 also noticed it this year, but thought it was less. Both of these persons noticed it on trees and fruit. Witness No. 70 said they have had trouble with the smut up to this year. They have a small ranch and noticed it on the stubble. The others did not complain of it.

CONCLUSION.

The people in the city itself do not have the opportunities for noting the smut that do those living on the ranches. An improvement in the amount of smut present for the last year or two has been noted, though the evidence is not as explicit on this point as in the case of the ranchers. So far as the main part of the city is concerned, it is not observed to any extent whatever. The same connection between the oil fumes and smut would seem to be indicated that was remarked upon with respect to the situation on the ranches.

DAMAGE TO STOCK.

There is little mention of damage to stock in the city of Benicia since the construction of the bag house. Witnesses No. 60 and 60A claim to have lost a horse some six or seven years ago, the symptoms being the same as with the other horses that were "smelted."

Witness No. 119 claims that when he was ranching some seven or eight years ago, he lost eight or nine head of horses, for which the smelter paid. These horses could not be worked, and had a bloody secretion from the nostrils.

Witness No. 44, a butcher, claims to have lost a horse some seven years ago. This horse was "smelted" in his opinion.

Witness No. 73 claims to have lost four horses some four or five years ago. Three of these horses were put in the pasture in the fall of the year and died in three weeks' time.

Witness No. 129 lost two horses four years ago, the horses roaring and displaying the usual symptoms. The horses were left out in the pasture over night. The horses have been kept in the stable over night since and no trouble has been experienced.

Witness No. 75 claims to have lost two or three cows and a horse, owing to the smelter. The time was placed as "several years ago."

The animals "just choked up and could not breathe, the horses getting fat and the cows poor." The condition of the animals was "just what the veterinarians have said was caused by the smelter."

Witness No. 64 claimed she has lost a number of chickens, owing to the smelter smoke. These chickens were all troubled with a "cough" before they died. The trouble continues up to the present time.

Witnesses Nos. 76 and 76A lost a cow this year, but the loss is not attributed to the smelter. Eight and ten years ago they lost two cows, the cows falling down to skin and bones. Now they believe these cows were "smelted."

Witness No. 69 lost several horses about six or seven years ago. These horses had been turned out to pasture and were affected "like the other horses." He has an old horse now, about 27 years old, that he believes is "smelted." This horse is "short winded," but does not blow much.

Witness No. 128 lost a couple of horses about 16 or 17 years ago. These horses were affected the same as the horses on the ranch of Witness No. 8, where he worked some years ago.

Witness No. 130, a teamster, lost a horse seven years ago that he considers was "smelted." It "was affected like the other horses around here."

Witness No. 70 does not know whether the smelter killed a cow and calf for them this year or not. The smelter "smelled awful bad" the night both died.

Witness No. 63 lost a horse last year and has another horse that he considers has been "smelted." The horse that died developed a cough and rapidly became worse until it died. The horse he now has is developing a cough likewise. He considers that the smoke is the cause of it. The horse that died was fed on hay bought from one of the local ranches, but his present horse is fed on hay purchased from the outside, so that he does not feel certain how the horse contracted the affection.

This completes the list of stock injuries complained of.

Witness No. 127 lost one horse nine years ago, and has two horses now that were "smeltered" before the bag house was constructed, he being unable to recall the year. His theory is that the sulphurous fumes irritated the mucous lining of the horse's throat and that the horse died of strangulation.

On the other hand, witness No. 131 has put his horse out to pasture for the past 20 years and never experienced any trouble. Witness No. 137 has had stock grazing out for 10 years past and has never had the slightest trouble. Witness No. 123 has had at least 10 head of horses grazing in pasture for the past 40 years and never lost a horse. Witness No. 61 has had no trouble with stock put out to pasture by them, according to their head teamster.

CONCLUSION.

Outside of the horse which witness No. 63 claims to have been "smelted" last year, there is no claim of damage to horses in the city within the past four years. Witnesses Nos. 73 and 129 claim to have lost horses four years ago, but the other losses of horses mentioned, except that claimed by witness No. 63, are prior to the operation of the bag house. There is no claim of any other stock losses aside from the cows that witness No. 75 claims to have lost "several" years ago, and except also the loss of chickens claimed by witness No. 64, which hardly deserves to be taken seriously. It will be noted that these cows got "poor," which is suggestive, considering the alleged existence of tuberculosis in the region.

The Selby plant is clearly not a nuisance so far as injury to stock in Benicia is concerned at the present time, and there is no basis for assuming it has been a nuisance along that line within four years at least, if not longer.

The conclusions reached with respect to conditions in Benicia proper thus coincide with those reached as to conditions on the ranches within the smelter zone in every respect.

In an investigation of this sort, where it is necessary to obtain the information in a short time from each witness, owing to the inability or unwillingness of witnesse generally to grant an extended interview, and where the gist of the answers can be jotted down only while new questions are being framed and put, there are many things that are developed and that impress an investigator that are not and can not well be recorded in a transcript of testimony, although they influence the conclusions arrived at. For this reason some general impressions may not be amiss.

It seemed to me that the question of a smelter nuisance at the present time is hardly a question at all. There is not a shadow of a doubt in my mind that the smelter can not be considered to be a public nuisance as the situation has existed for the past year, looking at things sanely and reasonably. I was firmly impressed with the idea that comparatively few people consider it to be much now, though there is a natural reluctance to say so for fear it should again become such. It seemed to me that the situation has been exaggerated in Benicia in the past and is still to some extent. The situation is unique in the claims put forth of great annoyance, but with no damage to vegetation proven.

RECOMMENDATIONS.

It appears to me that a great many of the residents of the smoke zone are not going to be satisfied with any conclusion the commission may reach unless some attempt is made to confirm or disprove some

of the current notions with respect to the damage or injury wrought by the smelter.

There are five different classes of such damage alleged and it is recommended that each one be investigated.

The first is the alleged injury to fruit trees and vineyards. The effort here should be made to ascertain what is the cause of the general condition complained of, rather than to establish whether or not the smelter caused or contributed to it.

The second is the alleged "poisoning" of the land, so that crops will not grow or the yield is diminished.

The third is the damage to stock. Witnesses Nos. 12, 63, 69, and 127 all have horses living that are claimed to be "smelted." The colts belonging to witness No. 12 and the horse belonging to witness No. 63 are claimed to be recently affected and should be examined by all means, as should the sheep belonging to witness No. 18 and the cows belonging to witness No. 1.

It is a rather peculiar fact that the evidence at the trial does not conclusively establish what the horses claimed to be "smelted" did actually. die from.

The fourth is the quick rusting and decay of wire screening, wire fencing, wire netting, etc., which is attributed to the smelter. This is considered to be tangible evidence of the capacity for harm of the sulphurous acid gases. This investigation should take in both the ranches and the city of Benicia.

The fifth is the origin and nature of this so-called smut or soot. This should be determined because of its fancied resemblance to lead and because of the psychological effect of the presence of this substance in the absence of knowledge of its nature.

A DETAILED STUDY OF STATEMENTS OF RESIDENTS OF THE CITY OF CONCORD, CONTRA COSTA COUNTY, CAL., AS REGARDS THE PRESENCE OF A SMOKE NUISANCE.

By C. B. Dutton.

I respectfully submit the following report of an investigation into conditions existing in the city of Concord, Contra Costa County, Cal., for the past three or four years:

The investigation was made at the suggestion of Mr. Braden, vice president of the Selby Smelting & Lead Co., who stated that it had been brought to his attention that there was considerable complaint in Concord about three years ago, but that this complaint has since ceased, although the smelter of the Mountain Copper Co. has continued to run as before. The idea was that the odor or smell which gave rise to that complaint might possibly have some relation to the oil fumes which, in his opinion, gave rise to the principal complaint in Benicia, inasmuch as the improvement was practically coincident with the capping of the oil stills at the Oleum plant.

The investigation was wholly negative as far as confirming this idea or belief is concerned. I arrived in Concord a few minutes before 11 a. m., having caught the 8 o'clock train from San Francisco, and left on the 6.30 train for the city. During my stay there I interviewed some 68 persons. Seventeen of these people had not lived in the town a sufficient length of time to be able to give me any information of value. None of these persons, however, had noticed any fumes or odors during residence in the city.

The testimony of the remaining 51 persons shows the following results:

32 persons never noticed any fumes or odors at any time.
9 persons noticed the fumes in Concord about three years ago.
2 persons noticed the fumes up to a year ago.
2 persons notice the fumes occasionally now.
2 persons complained of local odors such as sewer and slaughterhouse.
4 persons complained of noticing the fumes when driving toward Martinez a "couple" of years ago.

Of these 32 persons only 2 recalled hearing any complaint, but they were unable to tell me who the persons were that had complained, or in what part of the city they lived; the others did not recall ever having heard anyone make any complaint on the subject.

The above means that 38 out of 51 persons in Concord itself have no recollection of having noticed any fumes, odor, or smell attributable to the smelter or the oil refinery.

Of the 13 persons who have noticed such odors, all, without exception, say they came from Peyton (where the chemical works were located) or from the Mountain Copper Co. Several said that the fumes were worst when the Copper King smelter was running, which is a smelter of which I had not previously heard. This smelter was located around Bay Point, but just when it ceased to operate is something concerning which witnesses could give no information.

Eleven of these 13 persons identified the smell as sulphurous, the same as would be noticed at the smelter, and spoke of irritation and cough produced by the fumes. One, a druggist, called it a "chlorine" fume, while another could say only that it was a strong smell, the latter noticing this smell last year. Only three persons claimed that the fumes were very bad at any time, one of these persons claims still to notice the fumes, while the other two have not noticed them for a couple of years. All the others claimed that they noticed it but little; that it did not bother much. It is evident apparently from this testimony that the fumes were never much of any annoyance in Concord. Witness No. 1, a former mayor of the city, claimed there was considerable complaint several years ago, but he could not refer me to the persons who complained. Witness No. 2, a practicing physician, also made the same statement, but he could not recall who complained. I could not find very much evidence of this complaint.

It seems a little peculiar that there should have been more complaint three years ago than there is now or has been since, in view of the fact that the Mountain Copper Co. must be discharging as much sulphurous acid gas as before, if not more. Some reference was made to improvements that were made in the Peyton Chemical Works after the suit was begun against the companies some three years ago, and the elimination of the odor or smells, so far as most people are concerned, appears to date from that time. No recollection is had of any heavy oppressive odor that used to come in the room and stay there, or that was penetrating enough to arouse them from sleep, or that had a stifling effect. They all say it was not bad enough for that. Two persons say it was west winds that brought the fumes to them, while the rest say the winds were from the north or northwest, pointing in the general direction of the Bulls Head smelter and Peyton.

Four persons, among them witness No. 3, a leading merchant, spoke of the suit that had been brought against the companies by the supervisors, and said that an attempt had been made to include Concord in the fight, but that evidence could not be obtained show-

ing that it was a nuisance or that damage had been done, so that the attempt was given up. Two of these persons also said that the farmers who had made the greatest "holler" against the smelter had been unable to prove a case, and the suit had practically been dropped.

I also found that several of the townspeople referred to the farms nearer the smelter (Mountain Copper Co.) having been ruined, so that they would not grow anything, and this despite the fact that there are no lead deposits to "poison" the soil, as is claimed across the straits in Solano County. There does not appear to be a widely prevalent opinion of this sort, as the soil around Concord is remarkably fertile, a deep rich loam, according to general accounts, and crops are uniformly good.

So far as the times when these fumes were noticed is concerned, two persons claimed they were noticed along in the early evening, while the others say they came at all times. They were never present for any length of time, an hour being the most that anyone claimed. The others say they would just smell it for a short time.

The only thing that suggests the possibility of Mr. Braden's supposition being true is that the odors have been perceived only seldom in the past two years, and that most people who did notice them have not noticed them since. There is nothing else in the description of conditions that suggests the odors or fumes given off in the refining of oil. It seems more plausible that it came from the combined plants on the bay, rather than from Oleum, since there is more of a natural draw in that direction, while high intervening hills would have a tendency to prevent the oil fumes from carrying that far. There is an oil refinery at Bay Point, but whether that ever entered into the problem is indeterminable from the evidence at hand. There is no reason to believe it did, however.

There was one thing that impressed me, and that is, in this town of Concord, where it is evident there has been no nuisance worthy of the name, it would seem, on the face of the evidence, that it would be possible to reproduce exactly the same variety of opinion, and even some of the same vigorous complaints, that exist in Benicia to-day, where a nuisance has been declared to exist and is still claimed to exist.

In my judgment there is nothing in the way of tangible evidence that throws any light on the Selby problem.

CONDITIONS OF PLANT LIFE IN THE SELBY SMOKE ZONE, JANUARY 1 TO JULY 1, 1914.

By J. W. Blankinship.

INTRODUCTION.

It is to be noted that this investigation was not begun until January 9, 1914, in the district in question and was ended July 1, and that the time at my disposal for the work was very limited. I was able to give only 18 days of actual field work—an average of one examination each 10 days, while hardly more time was available for laboratory work on the material collected. Fortunately I had previously been over this district on several occasions and so was fairly well acquainted with the local conditions and the injuries commonly attributed to smoke. Consequently less time was required for my work than would ordinarily have been the case. The work was undertaken in anticipation that it would be completed by May 1, but the inauguration of the experimental fumigation work at Vallejo and Davis extended this period into July and necessitated frequent trips back and forth from Utah to California to keep in touch with the progress of the work. However, it is believed that the examinations were made frequently enough and so distributed throughout the whole crop season, fruits excepted, that my findings represent the actual present conditions existing within the area in question.

LOCAL CONDITIONS.

The district under observation lies in Solano County immediately north of the Straits of Carquinez and extends from Vallejo to Benicia, a distance of about 8 miles east and west and for some 3 miles inland. The country is hilly and rises gradually inland and connects with the Coast Range to the north. The soil is mainly adobe, deep mud during the wet season, dry and hard during the summer. The winds here are mainly from the west, and during the period of observation this was the prevailing wind for a large part of the time. The present season has been remarkably wet, occasional rains continuing almost up to July, so that the crops rarely suffered from lack of moisture. These moist conditions are particularly favorable for injury by smelter smoke. Such smoke injury as is reported will therefore be representative of the worst conditions that are likely to

occur in the area. The annual crops grown consist almost wholly of small grains, barley, oats, and wheat. Various fruits are grown in small quantities. Stock raising is also one of the industries in the district. It is all open country, with scattered clumps and rows of eucalyptus, occasional orchards, and the usual California shade trees and flowers, with frequent cypress hedges.

More or less vegetation remains green throughout the winter, so it is possible to follow smoke injury readily throughout the year. As soon as the rains begin in the fall the native vegetation greens the hills in a few weeks and is rankest in March, April, and May, rapidly drying up with the advent of the dry season, so that for a large part of the year the country is brown and bare except where water can be obtained or perennial growth exists. Irrigation is not practiced in this district to any extent. With a few exceptions the orchards are not depended upon as a source of income and do not receive the care and cultivation necessary for success in the growing of fruits in California. In consequence they are now badly infested with insect pests and fungous disease. These causes, together with improper care and cultivation and the prevailing drought of the last three seasons, have produced general unhealthful conditions in the orchards of the area, conditions that have been attributed to "smoke" by the residents of the "smoke zone." This "unhealthful condition" is not confined to Solano County by any means.

BOTANICAL METHOD FOR DETERMINATION OF SMOKE INJURY.

It is only within the past few years that the branch of plant pathology that deals with smoke injury to vegetation has been sufficiently developed to make accurate diagnosis possible. A brief explanation of its general principles may serve to illustrate the methods here pursued.

The diagnosis of smoke injury is based upon the study of the condition of the lesions produced by the agents of injury; the markings, shrinkage, and coloration of the affected parts of the foliage; the general plant health; the microscopical examination of the injured tissues, particularly the cell shrinkage and the condition of the cell contents, and on certain microscopical reactions to determine the nature of these contents. Usually an examination of the foliar markings is all that is necessary to determine the presence of smoke injury.

As a rule there are only three kinds of injury to vegetation found in the vicinity of smelters which are produced by their emanations, as follows: (1) Flue-dust injury to plants, due to absorption of poisons from the soil through their roots (see Pl. XXXII); (2) acid-spot injury to

stems, foliage, and fruit caused by drops of sulphuric acid, usually condensed about small particles of flue dust, which are precipitated from the smoke stream (see Pl. XXXII); (3) sulphur dioxide injury to the foliage—rarely to stems or floral parts—due to absorption of the sulphur dioxide through the respiratory system of the plant or, more rarely, directly through the epidermal cells (see Pls. XV, XXII, XXIX to XXXII, XXXV, and XXXVI). The conditions for injury are more favorable in moist or damp weather. This is the usual form of injury about most smelters, and the only one now found in the Selby district, as is shown by the leaf markings that have been studied.

The different species of plant vary greatly as to their susceptibility to sulphur dioxide injury, and each has its peculiar markings and coloration, which in many cases are very similar to those produced by certain fungous diseases and insect injuries; so that in the selection of "guide plants," "Fang planzen," [a] for the determination of smoke injury it is necessary to adopt those in which the smoke markings and coloration are most characteristically different from those produced by other agencies. It naturally follows that the smoke expert must be a plant pathologist, so as to be able to identify the common diseases and injuries encountered, which are liable to be, and, in fact, usually are, confused with those produced by sulphur dioxide.

Certain "guide plants," therefore, are selected. These should be plants most susceptible to smoke injury, species general over the region under investigation, in continuous foliage throughout the season, and those on which the smoke markings are most characteristic. In the "Selby smoke zone" it was found best to utilize for this purpose during the period of investigation the grains, the wild turnip, and the mustard, species not available after July 1. By means of these guide plants it is possible not only to determine the utmost limits of any smoke injury but also to make a fair estimate of the injury produced within any particular part of the area, as the relative amount of foliar injury corresponds in general with the diminution of crop yield. Many species of plants, however, appear to be able to suffer the loss of varying amounts of foliage without materially affecting the fruit yield, as, in a good season and with healthy plants, there is normally a considerable excess of foliage not necessary for the usual life functions.

In general it may be said of smoke injury produced by sulphur dioxide that it occurs on practically all the plants in a district that is materially injured—on some species more than others, and on a few, like the apricot and cypress, rarely ever. Therefore, in looking for smoke injury, suspicious markings on one or two species alone need hardly be considered, unless those species are known to be particularly susceptible to sulphur dioxide.

[a] Sorauer, P., Jahresb. f. Agrikulturchemie, 1900, p. 456; Haselhoff and Lindau, Jahrg. 31, 1903, p. 120.

Injury to leaves by sulphur dioxide is evidenced, usually, in the form of intercostal spots and lines, and the principal veins normally stand out green in the dead areas, the coloration extending to the tips and margins with a more intense injury, though in a few cases the tip or marginal coloration is produced first. The color of the dead parts is usually white, yellow, brown, or red-brown, with intergradations, never black or pure red. It usually takes one to three days after injury for the color changes to be complete. The first injury is nearly always a faded yellow green, usually accompanied with wilting. There is never any actual "corrosion" or eating away of the tissue by sulphur dioxide, though in a few species, like the plum and chokecherry (*Prunus demissa*), the dead areas tend to shrink laterally and tear away from the green tissue adjacent, frequently forming holes in the leaves. Nor does sulphur dioxide ever in the smelter districts examined, and in the many experiments observed, have any effect upon the normal fertilization of the plants, except secondarily, through the foliage destroyed or, with intensest injury, in the actual killing of stems and flowers, an occurrence rare, except in the laboratory.

Two kinds of sulphur dioxide injury are generally recognized among smoke experts, particularly in Germany, where the subject has been most carefully studied:

1. Acute injury, sometimes termed "visible" injury from its pronounced markings, both on conifers and deciduous vegetation. (See Pl. XXXVI.) This is usually produced by single or repeated "visitations" of strong sulphur dioxide and is that most usual about smelters.

2. Chronic injury, sometimes referred to as "invisible" injury from its more indistinct markings. (See Pl. XXXVI.) This has been noted only on conifers, and more particularly in the lee of large manufacturing cities, where dilute sulphur dioxide is almost constant in the coal smoke arising from the manufacturing industries.

Strictly speaking there is no evidence of such a thing as "invisible" injury, that is, an injury affecting growth and yield, but yet not showing in the general health of the plant nor in foliar injury. The unfortunate term "unsichtbare Beschädigung" is employed by the Germans only as a synonym for "chronic injury" and is used to describe particularly the unhealthy condition of coniferous forests long subject to dilute sulphur dioxide influence, an injury that is certainly "visible." The term "chronic" or "invisible" injury has not, so far as I am aware, ever been applied by German investigators to deciduous trees and shrubs or herbaceous plants.

As a rule, the injury from smelter smoke is greatest in the path of the prevailing wind drift and occurs more frequently in damp weather. The "smoke zone" in some localities is confined to a small

angle in one direction from the industrial plant causing the injury; in others it is radiate, with the source of emanation at the center; in still others it is more or less circular or elliptical, the area being determined by prevailing winds and the land contours. Neither does the smoke "skip" certain areas and "drop down" upon another beyond to do material injury, unless a hill or forest be interposed, though with a high stack the injury is often less immediately adjacent. The smoke drift is always in straight lines with the wind, except as modified by land forms, and the injury normally diminishes directly with increase of distance from its source. A prevailing error in regard to smelter smoke is the supposition that the "bleached" vegetation is harmful to stock. It was once generally supposed in England that the vegetation injured by smelter smoke could be distinguished by its acid reaction,[a] but while this may be true possibly with wet foliage freshly injured, it appears certain that any such acid is fully neutralized and "fixed" by the plant in the process of injury and that the final condition of such bleached vegetation when dry is apparently not essentially different from that of uninjured plants after they have been cut and dried as "hay." Indeed, the "cooking smell," often mentioned as characteristic of crops freshly injured by sulphur dioxide, is that noted in fields of new mown hay of the same species and is merely the odor incident to drying. The bleached vegetation is not injurious to stock.[b]

INJURIES BY FUNGI AND INSECTS IN THE SMOKE ZONE.

The distinction of fungous diseases from sulphur dioxide injury is rarely difficult. Most plant diseases are well known and described in works on plant pathology. Leaves suspected of smoke injury and not sufficiently characterized by external markings and coloration may be sectioned and the tissues examined under the microscope. If the injury is caused by fungi, the characteristic fungous filaments will be found in or among the cells or on the surface of the leaf, or their fruiting spores can usually be seen. (See Pls. XXXIV and XXXVI.) If the disease is of bacterial origin, the bacteria will be found in the tissues. In case the injury is caused by sulphur dioxide these fungous hyphæ are normally absent, the cells are greatly contracted dorsiventrally, and the cell contents are homogeneous and arranged in plates or bands. This refers to sulphur dioxide lesions observed within a week or two after injury and after the color changes incident to the chemical reactions involved and the subsequent drying are complete. In time, under moist condi-

[a] Hamburger, S. Injury done to vegetation by gases arising from certain manufacturing processes: Jour. Soc. Chem. Ind., vol. 3, 1884, p. 202; abstracted in Jour. Am. Chem. Soc., vol. 6, 1884, p. 198.

[b] Widtsoe, J. A., The relation of smelter smoke to Utah agriculture: Utah Agr. Exp. Sta. Bull. 88, 1903, pp. 167-177; Merrill, L. A., ——, Western Chemist and Metallurgist, vol. 3, 1907, p. 59.

tions furnished by dew and rain, various saprophytic fungi, particularly *Cladosporium herbarum*, are apt to attack the foliage killed by sulphur dioxide, and these should not be mistaken for the cause of the injury.

Insect injuries to the foliage are even more easily characterized, as insects bite away the tissue externally or internally or puncture the cells to procure their food, and the insect itself, its eggs, or excreta, is usually found with the leaf to show the cause of the injury.

THE CYPRESS DISEASE.

The browning and death of the Monterey cypress, so general in all this district, is the most puzzling of all the abnormal conditions observed in the "smoke zone," and it is but natural that the residents should attribute the effects produced by this obscure malady to "smelter smoke."

In nearly all parts of the "smoke zone" of Solano County the Monterey cypress (*Cupressus macrocarpa* Hartw.) is now dying or dead, and the brown and dead branches and trees are found scattered among the living, in great contrast to the beauty of this species in most other parts of the State. This is most noticeable in and about the Vallejo cemetery, the Deming and Corcoran ranches, and parts of the district immediately north of Benicia, but it seems to be rare in the towns of Vallejo and Benicia themselves. Fully half the trees in the "smoke zone" are more or less affected.

In general, the affected trees are characterized by a gradual paling and browning of the green leafy twigs extending from below upward, the tips of the branches being the last to die. Small trees die solidly throughout, preceded by a general yellowing of the foliage; larger trees die in piecemeal, by separate branches, till the whole tree is dead. Often there is an accompanying rot of the lower bark and roots, while the affected trees seem to be always distinguished by a white flocculent deposit on the bark from a scale insect or by patches and streaks of exuded gum flowing from insect borings in the bark. This injury has now continued for several years and is clearly due to the gradual impairment of the vitality of the trees.

The problem was to determine whether this gradual impairment and death of the trees was due to smelter smoke, with the fungi and insects being incidental thereto, or whether the latter were the direct cause of the death of this important California shade species.

That the injury was in nowise due to smelter smoke appears from the difference in the character of injury. In injury to trees by sulphur dioxide, the tops of the trees and the tips of the branches usually die first, while short adventitious shoots appear toward the base of the branches and on the trunk—just the reverse of the injury here. Moreover, the Monterey cypress is one of the most resistant of species

to sulphur dioxide, and I can recall no case of material injury to this species by sulphur dioxide even in districts almost swept bare of other vegetation by smelter smoke. It is only necessary to instance the row of cypress trees on the bluff above Vallejo Junction, within a quarter of a mile of the Selby smelter, and frequently in the line of direct smoke drift, where nearly all other species show bad injury and even the resistant eucalyptus is dying or dead, and the cypress trees growing within a hundred yards of the smelter in the town of Selby itself. Also, conifer leaves and needles normally turn a bright red brown ("burnt sienna" color) when killed by sulphur dioxide, while the green leafy twigs of the cypress in this disease turn yellow and light brown on dying. Furthermore, the diseased condition is by no means confined to the district within which smelter injury is alleged, but extends northward at least to a point between Elmira and Dixon in the Sacramento Valley and southward to Sobrante, near Giant, in Contra Costa County, but the exact geographical limits where the disease occurs have not been determined. Neither is the injury always or mainly "on the side next the smelter," as careful observation has failed to show that any side of the tree is specially favored. Sections of the affected leaves and branches show no characteristic markings of any smoke injury under the microscope.

So far as I can determine there are several agents contributing to the production of this "cypress disease," but the time allowed for this investigation has not been sufficient to solve the problem completely. Examination shows that many of the trees still alive and most of those dead are affected by a wood-rot fungus (*Coniophora cerebella*, Schw.[a]), which attacks the roots, bark, and sapwood of the lower trunk and causes rapid decay, so that the trees are apt to blow over soon after death. This has caused the removal of most of these trees from the Vallejo cemetery. However, many of the trees found dying or dead seem to have no trace of this disease and the roots and wood are quite sound, as is shown in removing the trees from the cemetery, so that this can not be the efficient cause of the disease in most cases.

Sections of the dying leafy twigs in some cases have shown bacteria and fungous hyphæ in the cells and tissue, but these are not sufficiently abundant to play much part in the disease, nor are they always present in the dying twigs. They are usually found only in the dead tissue, as saprophytes. No other fungi, so far as I have observed, are commonly present or in sufficient abundance to cause the injury.

Many assign the death of the trees to the drought conditions that have prevailed in California for the three years previous to the present season. Some of the trees in the smoke zone are certainly dying from this cause, particularly those in the arsenal grounds east of

[a] Determination of Prof. Horne.

Benicia, and occasionally in dry situations elsewhere. Trees so dying resemble in many respects those dying from the disease, while the two though distinct, are commonly confused, and are not easily separated except by the presence of this wood-rot fungus or the insect pests hereafter mentioned. Also, it appears that the trees in the lowest places are apt to be first attacked, as seen on the Dos Reis ranch and in the grove at the bottom of Elliott Cove. It is also evident that if the disease were due to drought conditions, it would be found general over the State. This is certainly not the case. So far as I am aware, it has not been noted outside the district mentioned. Hence, though drought may aid the spread of the disease by reducing the power of resistance to these pests, it can hardly be the efficient factor. As a rule, where the cypress are found dying from drought, most other trees will be similarly affected.

All the cypress trees I have examined, not clearly dying from drought or other natural conditions but showing the general characteristics of this disease, appear to be infested by one or two insect pests, usually both in sufficient abundance to cause the unhealthy condition characteristic of the disease. In fact the "disease" appears to arise mainly from a combination of the work of these two insect pests. The one causing the most rapid destruction is a bark borer (*Phloeosinus cupressi* Hopk.[a]) which appears to attack perfectly healthy trees. If the tree is small, it dies rapidly. As a result of the girdling of the larvæ, streams of semiliquid gum exude from the holes in the bark and run down the trunk; the leaves of the whole tree turn first yellow, then brown as it dies. In large trees only the branches are thus attacked and the ravages of the insect are indicated by the scattered dead branches with more or less gum flowing from the wounds, while the bark, on removal, shows the tracings of the insect beneath. An instance of the first kind of injury is shown in the row of young trees on the north side of the Vallejo-Benicia road not far from the experiment station, as shown in Plate VI, and between this and the cemetery, where some 8 or 10 trees are dying from this cause. The row of trimmed cypress in front of the Carquinez cemetery shows the second kind of injury.

However, the most general and widely distributed injury, but where the death of the trees is very slow, unless aided by the first, is that due to a scale insect (*Sphaerococcus cupressi* Ehr.), which excretes a small amount of cottony tomentum, just sufficient to make its presence evident on the infested trees. This appears to cause a gradual decline in the vitality of the tree or branch and the gradual death of the foliage, the tips of the branches being last to die. In this condition the tree is readily attacked by the wood borers and

[a] Determination of Prof. R. W. Doane.

parasitic fungi, but may linger along for several years before death, unless these supervene.

It therefore appears that the "cypress disease" is caused by a combination of several injuring agents in the district in question and is probably not due wholly to any one, though the scale insect is the one most usually found. It is certain that the smelter smoke has nothing to do with the trouble.

THE SOOTY DEPOSIT ON PLANTS.

A common phenomenon throughout the smoke zone is a black, sooty deposit (fig. 14) on plants, more usually on the leaves, but often on the bark and even the fruit occasionally. This deposit is more frequently found "on the side next the smelter" in common opinion and so is naturally believed to be due to "smelter smoke." It is often massed densely on the under side of the thicker evergreen leaves, like the olive, and even occurs on grain, but without any actual injury being apparent. To the eye it strikingly resembles soot, but under the microscope it is found to be composed of black, closely adhering, angled or rounded cells with fungous filaments often extending outward from the masses and even penetrating the dead tissues of the leaf or bark (1 and 2, fig. 14), very different from the amorphous angular masses of soot (3, fig. 14), and clearly of fungous origin. This "sooty mold" (*Apiosporium salicinum* Kze., capinodium, and related forms) is common, not only in California, but all over the world, particularly near the sea where the air is damp, and it has no relation whatever to smelter smoke. It is strictly epiphytic, causing no disease, and its hyphæ rarely enter the live tissues of the host plant. It is called "Russtaupilze" or "Schwärze" by the Germans and "Fumagine" or "Noir" by the French, and the fungi are abundant wherever honey dew is excreted by aphis or scale insects, as in the case of the black scale of the olive. It is here mainly on the "side toward the smelter," because this is the direction from which the damp ocean winds blow. Further information can be had by consulting Stevens, F. L., The fungi which cause plant disease, 1913, pp. 191–195; Sorauer, Paul, Handbuch der Pflanzenkrankheiten, vol. 2, 1911, pp. 199–202; Prilleux, É. E., Malades des Plantes Agricoles, vol. 2, 1897, pp. 42–62.

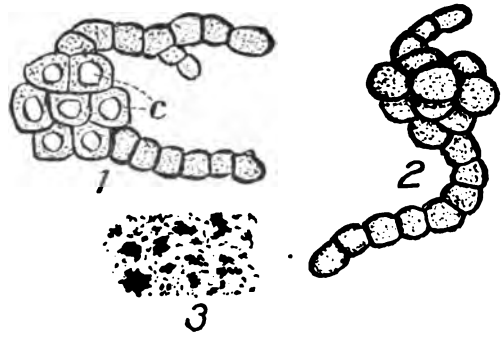


FIGURE 14.—"Sooty mold" and soot highly magnified. 1 and 2, sooty mold with some plant cells, *c*; 3, soot, similarly magnified.

THE BACTERIAL BLIGHT OF BARLEY.

This disease develops on barley, to a greater or less extent, wherever cultivated, but much less frequently on other grains and grasses. In appearance it wonderfully resembles forms of sulphur dioxide injury and only the microscope can distinguish it from that injury in its early stage, though the later browning is fairly characteristic. The blades of barley are "bleached" or yellowed in spots and streaks and often finely mottled like those injured by dilute sulphur dioxide, and these spots tend to enlarge and spread till the whole leaf may be killed. In later development, the "bleached" areas are bordered with a fine dark-brown line or streak next the green; or the smaller spots may show brown from the first. Sections of the spots under the microscope usually show abundant bacteria in many of the affected cells. The disease is caused by the presence of the symbionts *Pseudomomus avenae* Manns and *Bacillus avenae* Manns that appear to work together to produce the injury.[a] A curious fact regarding this disease is that it tends to develop on the injured parts of blades slightly damaged by dilute sulphur dioxide and can be distinguished externally from this injury only by the browning that later appears. Where this bacterial disease develops extensively, as it does occasionally on barley and oats, it is certain to be mistaken for smoke injury to these plants, if it occurs in the vicinity of a smelter. The disease is frequent and general in the district investigated, as well as in other parts of the United States not adjacent to any smelter or industrial plant.

THE HELMINTHOSPORIUM DISEASE OF BARLEY.

A frequent fungous disease on barley, oats, and some of the wild grasses in this district is the so-called "late barley blight," due to the fungus *Helminthosporium sativum*, Pammel, K. & B.,[b] which in the earlier stages of the disease strikingly resembles the mottling of sulphur dioxide and can be distinguished from it only by making sections of the injured leaves and noting under a microscope the fungous hyphae in the tissues, or the spores that usually develop after the death of the leaf. The disease not rarely becomes epidemic and does considerable damage to the grain, as was the case in one instance on the Dos Reis ranch. A very similar disease, *Helminthosporium gramineum* Ernk, in which the apparent "bleaching" is in long streaks on the leaves, instead of in spots, is also frequent in the fields examined and not rare on the wild barley grass and wild oat. These diseases and the bacterial blight, also common on barley,

[a] Stevens, F. L., Fungi which cause plant disease, 1913, pp. 23-24, 40; Manns, T. F., The blade blight of oats; Bull. 210, Ohio Agr. Exp. Sta., 1909, pp. 91-166.

[b] Pammel, L. H., King, C. M., and Bakke, A. L., Two barley blights, with comparison of species of Helminthosporium upon cereals: Iowa Agr. Exp. Sta. Bull. 116, 1910, p. 182.

render it unreliable as a "guide plant" in any region where smoke injury is suspected.

THE SHOT-HOLE DISEASE OF STONE FRUITS.

This disease, due mainly to the fungus *Coryneum Beyerinckii* Oud., is usually destructive in this whole district, and the holes in the leaves are frequently pointed out as "smoke injury" on the apricot, cherry, peach, almond, prune, plum, etc. In early spring the tips and margin of the young leaves, particularly of the almond, are browned and killed, but later the disease shows in the form of many small holes in the leaf, in the case of the peach usually accompanied with a bright red coloration and premature leaf fall. The popular impression that such holes are "smoke spots" that have been formed or been eaten out by the acid of the smoke has no foundation in fact, except in the case of thin-leaved plums where the dead tissue frequently does fall out and leave similar holes. In beets, radishes, cabbage, and turnips badly injured by sulphur dioxide the dead tissue frequently rips out or is torn away, but always with more or less tissue left in place to distinguish the injury. There is no smoke injury of this nature anywhere in this whole district. There is no question but that the leaves with holes in them are affected with this Australian shot-hole disease, or are eaten out by insects, just as they are in most other parts of the State. Sections of the dead tissue will often show the characteristic spores. In the case of garden vegetables like cabbage, turnip, radish, etc., with such holes, the cause is here found in the cabbage worm or the larvae of other biting insects, which will usually be found on the under side of the injured leaves.

OTHER FUNGOUS DISEASES.

WOOD-ROT FUNGI.

Wood-rot fungi of many species of Basidiomycetes enter the wood of trees through wounds or bark sunburn, and cause by their spread in the bark or wood the ultimate death of their host. These are usually recognized by the white felty filaments in the wood and bark and by the "toadstool" excrescences on the surface, forming the fruit of the fungus. The peach, almond, prune, apple, pear, cherry, cypress, eucalyptus, and most of the other trees generally grown for fruit or shade are subject to these wood-rot fungi. Trees dying from these causes are commonly referred to as "killed by smelter smoke," even when the fruiting bodies are plainly evident on the bark. In many cases it is only by cutting down the tree or digging about the roots that this rot can be shown to be the cause of the trouble.

PEAR BLIGHT.

Pear blight, affecting both the apple and pear, is now so generally known that its recognition should not be difficult, yet this is frequently pointed out as "smoke injury" by orchardists of the smoke zone, who have not yet learned to recognize the blackened twigs and fruit and the dead bark on trunk and branches, which are characteristics of this disease.[a]

GROWN GALL.

Grown gall also occurs to some extent on the roots of various trees, like the almond, apple, peach, and prune, and may seriously affect the health of the affected trees. In this case the cause may be obscure and may often be found only by digging away the earth from the roots.

GUMMOSIS.

Gummosis of the cherry, almond, and peach is also common here, and is frequently fatal, particularly to the cherry. The yellowed leaves and exuded gum on the trunk or branch indicate the trees affected.

LEAF CURL.

Leaf curl of the peach and almond occurs frequently, but the thickened, contorted leaves bear no resemblance to any form of smoke injury.

BLIGHT.

Blight on barley and certain wild grasses causes spots and lines on the leaves not readily distinguished from smoke injury by the eye, but under the microscope the hyphæ in the tissue and the spores of the fungus (*Helminthosporium*), described on page 390, can be recognized.

MILDEW.

Mildew (*Peronospora trifoliorum* De Bary) causes an apparent yellowing or "bleaching" of the leaves of clover and alfalfa, liable to be mistaken for smoke injury, but the fungus can usually be recognized as a felty mass on the underside of the leaf, even with a low-power hand lens.

A species of Macrosporium was found to be killing the tips of alfalfa in Benicia. It was pointed out as probable smoke injury by some of the residents.

DOCK DISEASE.

The dock disease common over this district is due to the fungus *Ovularia oblique* Sacc., which shows on the leaves of the common

[a] Smith, in 1909, reported this disease to be worse in Solano County than in any other part of the State; Smith, R. E., Report of the plant pathologist to July 1, 1906: Cal. Exp. Sta. Bull. 184, 1909, p. 229.

dock (*Rumex crispus* L.) as small round yellow spots with purple margins (see Pl. XXXIII). "Acid spots" on this species are brown.

HOLLYHOCK DISEASE.

The hollyhock disease (*Puccinia malvacearum* Mont.) spots the leaves of hollyhocks and of *Malva rotundifolia* generally throughout this district.

In the whole section under observation this spring it was observed that many of the lower leaves of the grain crops, particularly barley, yellowed prematurely, that is, became bright yellow throughout, even when the grain was not in a low situation. In the field where the fumigation experiments were carried on an abnormal yellowing of the lower leaves was noted. This coloring in other fields was unquestionably blamed to "smoke" by the farmers, yet sulphur dioxide had nothing to do with it. Later, as the blades died, the spores of *Cladosporium herbarum* Lk. abundantly developed on the dead leaves and it is probable that this fungus, usually a saprophyte, had here become parasitic during the remarkably wet season and caused the injury.

These are some of the common fungous diseases frequently mistaken for "smoke injury" in the Selby smoke zone.

INORGANIC INJURIES.

Inorganic injuries are much more difficult to recognize and to distinguish from sulphur dioxide injury than those classed as organic diseases. The tissue is neither punctured nor eaten away, nor does it contain the fungous hyphæ or spores. In some cases, like fire injury and sunscald, it is extremely difficult to find any certain means of distinction, even under the microscope. Fortunately there was little of this class of injury, while where it did occur the small area affected and the local conditions served to show its cause.

FLOODING.

Flooding was common in early spring and the grain under water later developed an unusual amount of yellow leaves. This abnormal yellowing of the foliage was sometimes attributed to smelter smoke by the residents of the "smoke zone." The uniformity of coloration and its occurrence only in low ground made it clear that the trouble was brought about by flooding.

DROUGHT.

Drought, on the contrary, was rare during the period of observation, but its effects, from the several dry seasons of the years immediately previous, on all kinds of trees in the district was plainly evident.

It was most pronounced in the arsenal grounds east of Benicia and on the higher hills over the whole district. In particular it developed a peculiar eucalyptus disease, always, here, pointed out for smoke injury. The leaves became white-mottled or brown on the tips and margins, and often intercostally, singularly like forms of sulphur dioxide injury, but unquestionably due to the drought conditions and the hot winds. The injury frequently showed in low ground, where the usual water supply had completely failed, and also appeared sometimes on dry rocky hills, like that on the road just north of Benicia. The same appearance was found on the eucalyptus at Palo Alto and in the north part of Berkeley, as well as in other parts of the State, to a greater or less extent, so that its cause can hardly be questioned.

Similarly, in the same situations, the tips of the pine needles turned brown, the margins of the leaves of the acacia died and the cypress browned and died, much as in the case of the "cypress disease" mentioned before. A similar dying of orchard trees was observed in a few instances, but where cultivation was practiced this was largely prevented. The same conditions prevailed elsewhere in the State with similar soil and situation, so that the smelter smoke was not concerned with this form of injury.

IMPROPER CARE.

Improper care, or rather lack of care, was frequently responsible for the condition of orchards, where smoke injury was alleged. A general lack of spraying, poor cultivation, frequent pasturage, improper soil for the several species, lack of drainage in some cases—all went to make up the unhealthful condition found and frequently ascribed to smelter smoke by the residents of the smoke zone.

FIRE.

Fire injury closely resembles that of sulphur dioxide and was found where prunings had been burned or grass fires prevailed. However, such injury showed only on the lower leaves and branches of the trees, instead of on the uppermost, as in smoke injury. It was usually more on one side of the tree and that often not "the side next the smelter."

FROST.

Frost injury was pointed out in a few cases as that due to "smoke," but the difference in coloration and markings is always distinctive.

Failure of fruit to "set" is always alleged in the smoke zone to be caused by the smelter smoke, but is clearly due to cold ocean winds, to rain at the time of blooming, or to "cold spells" or unusual hot winds after the fruit has set, causing it to fall off. This same trouble

is common in all parts of the State where similar climatic conditions prevail. Smoke does not normally in any way affect fertilization or cause the fruit to drop off, except in cases of very severe sulphur dioxide injury, where a large part of the foliage of the tree is killed and falls off, thus preventing the usual food supply. That smelter smoke will affect the fertilization of plants and the setting of fruit without other visible injury is a popular idea, but has no basis in fact. The smoke from the Selby smelter has not the slightest effect upon fruits or the yield of cereals in this district.

NATURAL CONDITIONS SOMETIMES MISTAKEN FOR SMOKE INJURY.

LEAF MATURITY.

Leaf maturity, the usual yellowing and death of the lower leaves of grain and grasses and the older leaves on trees, has been frequently pointed out as due to smoke, but it is necessary only to check up this condition in other districts far removed from any possibility of smoke contamination to see that there is nothing abnormal about it. The absence of the usual sulphur dioxide markings of the species shows that the smoke has nothing to do with the "injury."

In early spring the young foliage and shoots of the eucalyptus in the smoke zone naturally assume a peculiar brownish green and the same is often seen on young orchard trees, like apricot, which is pointed out as "caused by smelter smoke." This is a good instance of the lack of observation of some people who see these things, just as they do frost injury, all their lives, and yet notice them only when they are expecting something abnormal from the "smoke."

Another case called to my attention was a peculiar browning of certain cypress trees in spring, which was instanced as "smoke injury." Examination showed that the trees had only come into bloom, just as they had every year since the party had owned the place, and yet before went unnoticed.

Also vines exposed to the cold ocean wind do not bud as early as those on the sheltered or sunny side of buildings "away from the smoke," and this has been indicated on several occasions as caused by the smelter smoke.

SMOKE INJURY IN SOLANO COUNTY.

The northern shore of the Carquinez Straits is distant about 1 mile to the northeast of the smelter. Here along the shore, which is bordered with steep hills and an occasional indented "cove," careful watch has been kept for approximately six months to see whether any form of smoke injury could be found on the vegetation, while occasional trips were made farther inland for the same purpose. The

dates of these several examinations are January 9, 10, and 30; February 26; March 9, 12, 21, 24, 26, and 28; April 2 and 20; May 11 and 31; June 3, and July 1, covering the period when the usual crops are in the field, the rains most frequent, and the vegetation rankest and the period when smoke injury would be found if it occurred at all.

Inasmuch as the smoke drifting across the straits directly against these coastal hills would do more damage here than in any other part of the district, much less attention was given the section lying north of the Vallejo-Benicia road. However, the coast line itself, particularly that from Dead Mans Point to Glen Cove, was closely observed on most of the occasions mentioned. Frequent examinations were also made around Benicia.

At one point about halfway up the hills and about half a mile east of Dead Mans Point unquestionable minute traces of sulphur-dioxide injury were found on the young vegetation on two occasions—January 30 and February 28. This injury was found after rain and when the soil was still wet. The injury here was so slight that it would have gone unnoticed by the casual observer and in fact was not reported by any resident of the smoke zone. On March 24 and 28 a few sulphur-dioxide markings were observed on the weeds at station 1, near the "old mill" in Benicia, 4½ miles east in direct line from the smelter. Here again the injury was slight and inconspicuous and the smoke did not affect wheat or fruit trees near by. At one time, April 20, a field of barley of some 15 acres, on the hill to the northwest of Dos Reis Cove, showed strong yellow and brown mottling, remarkably like injury from dilute sulphur dioxide, which was at first mistaken for such. Later microscopic examination showed it to be a form of Helminthosporium bacterial blight, with the characteristic lesions of smoke injury absent. All other injuries to plants in the entire smoke zone were found to be due to agencies other than smelter smoke.

It is therefore possible to say with certainty that, except for the slight traces of sulphur-dioxide injury in the two localities mentioned, the smoke zone has been entirely free from any actual smoke injury to vegetation during the period of observation and that the fears of the farmers that the conditions in the smoke zone were due to smelter smoke are unwarranted. The conditions are due wholly to other agencies, mainly insect pests and fungous diseases.

As to the fact of past smoke injury to this district, it is not now possible to determine with certainty. However, a row of eucalyptus trees on the ridge to the east of Dos Reis Cove has been badly injured sometime in the past, apparently by fire, possibly by smoke coming from the west. Their tops are still in bad condition. The eucalyptus grove in the same cove and directly across the straits from the smelter

NATURAL INJURY BY SULPHUR DIOXIDE TO LEAVES.
1, Eucalyptus (rather old injury); 2, Turnip; 3, Nasturtium.

NATURAL INJURY TO LEAVES OF TREES BY SULPHUR DIOXIDE.
1, 2, Apple; 3, 4, Pear; 5, Plum.

NATURAL SULPHUR DIOXIDE INJURY TO LEAVES.
1, Grape; 2, Potato; 3, Rose; 4, Tomato.

NATURAL INJURY TO LEAVES BY SULPHUR DIOXIDE AND FLUE DUST, AND BY SPOT.
1, Asclepias Speciosa Torr.; 2, Helianthus Annus L.; 3, 4, Apple Tree Leaf;
5, Injury by SO_2 and H_2SO_4 to Plum Tree Leaf.

and much nearer shows nothing indicative of smelter-smoke injury, but considerable fire damage. The adjacent pasture lands here seem to be subject to late summer-grass fires. Another row of eucalyptus in Glen Cove also shows injury to the tops of the trees sometime in the past, which may have been caused by fire or smoke. The injury to these eucalyptus trees is not of recent date and appears to date back several years at least. The cypress trees in the Vallejo cemetery have certainly not at any time been injured by smelter smoke nor have the orchards and vineyards of the smoke zone ever been materially affected. The injuries causing their unhealthy condition or death are clearly from other and natural causes in all cases examined.

In all my trips through the smoke zone I have only once been able to distinguish the odor of sulphur dioxide, and then only for a few minutes and very faintly, at a point about 2½ miles northeast of the smelter. Sulphur dioxide to do material damage in dry weather to vegetation within half an hour must be so strong as to be almost unbearable, or if dilute must be very frequently repeated or almost constant over the area injured in order to affect vegetation at all.

THE OCCURRENCE OF SULPHUR DIOXIDE INJURY TO PLANTS IN THE SELBY SMOKE ZONE.

By Wyatt W. Jones.

INTRODUCTION.

The so-called "Selby smoke zone" consists of a strip of land along the bay or straits between the city limits of Vallejo and the eastern part of the city of Benicia and extending inland about 3½ miles to the northeast.

During the period of my investigation (from March 12 to May 8, 1914) no attempt was made to procure first-hand information as to the extent of the region involved, nor as to the nature of the allegations of the residents. In fact an effort was made to avoid conversations with farmers and others living in the region in order that the report might be based entirely upon actual conditions observed in the field.

Two to three visits to the region were made each week. Some time was spent about the Vallejo fumigation station and two days were consumed in traversing the road that forms the extreme northeastern boundary of the area, but the greater part of the time was spent in studying conditions on the farms along the Vallejo-Benicia road and between that road and the water front. Weather conditions were rather variable, and it was thus possible to observe the vegetation under variable atmospheric conditions with respect to humidity, temperature, and intensity of illumination.

My report deals with the occurrence of sulphur dioxide injury, the common fungous diseases, the presence of insect pests, the nature of the soil, the cultural methods and practices, etc. As the plant pathologist is concerned with all conditions that influence the health of plants, it was necessary to include this wide range of topics. Not only were the cultivated crops, trees, and ornamental plants observed, but also the native species, that is to say, the vegetation of the region was the subject of the studies.

Botanical specimens were taken on the various farms visited and along the roadways. Reproductions of photographs of certain of these specimens are shown herewith.

CONDITIONS ON PROPERTY OF WITNESSES NOS. 1 AND 1A.

The property of witnesses Nos. 1 and 1A comprises 1,150 acres lying partly in sections 19, 20, 29, 30, 31, and 32, or extending from the southeastern limits of Vallejo to a point approximately half way between Elliotts Cove and Dos Reis Cove, and from the water front to the Vallejo-Benicia road, No. 78.

This property is the largest and, for the present season or that part of the season included in the writer's investigations, by far the most important of those places over which the emanations from the Selby smelter pass, at least in so far as possible damage is concerned.

At the time of the first visit to the region, March 12, 1914, the limits of the property were not determined, and no examination of the crops was made other than an observation along the road above indicated. In front of the residence that stands opposite the property of Philip Steffan and in the northernmost part of the tract a small alfalfa plat was found to be in normal condition. Wheat and volunteer grain along the road farther eastward were very uneven, mostly considerably less than 6 inches in height, though more than a foot in spots. Barley and oat plants were scattered through this field, but no pathologic conditions were exhibited by any of the varieties.

On March 16 the grain had reached a height of 6 inches in general, though in spots it was as high as 18 inches, especially in the corner near the residence. A very careful examination was made of all the varieties of grain in this field and of the native vegetation for evidence of smelter smoke injury, but not the slightest suggestion of this condition could be found. Four or five blades of the tallest culms retained a good proportion of their green tissue. The lower blades were dead.

On April 7 the average height of the grain was about 12 inches in the corner nearest the residence. No pathologic conditions of importance were present. The grape vines about the residence were putting out a few shoots.

On April 11 a visit was made to the southermost part of the property or that adjacent to Dos Reis Cove. Behind the grove of eucalyptus trees in this cove very marked and unmistakable signs of smelter-smoke discoloration were found on native species, including broncho grass (*Bromus maximus* Desf.), soft brome (*Bromus hordeaceus* L.), common chickweed (*Stellaria media* Cyrill.), wind-mill pink (*Silene gallica* L.), poor man's weather glass (*Anagallis arvensis* L.), and burr clover (*Medicago denticulata* Willd.). The latter was slightly affected, whereas the Anagallis was prominently discolored. The discoloration of the brome grass was intermediate.

On the point of the hill north of the eucalyptus grove young barley 6 to 9 inches high was found to be noticeably affected by the smoke

from the smelter (see Pl. XXXV). However, one not in search of smoke markings would readily have passed without detecting any unusual condition. The markings consisted of fine spots commonly accompanied by a dark stain, identical with the markings produced in the fumigation tests. There was scarcely a blade that showed the usual bleaching resulting from smoke injury. Through this grain, blades of broncho grass were quite generally more than half bleached and even entirely bleached.

Along the border of the field wild-oat blades were prominently bleached and discolored, the bleaching often streaked in character. Here also the broncho grass was affected as in the open field. A luxuriant growth of black mustard in connection with the oat and grass blades was almost entirely unaffected. A few doubtful markings were noted.

On the steep slope above the water and facing the smelter other native species, including Eriogonum and lupine, were slightly affected. The lupine was also noticeably discolored by several species of leaf-mining insect larvæ (see Pl. XXXVI). The Eriogonum was badly damaged by a moth larva of the family to which the codling moth belongs. These conditions heightened the effect of the smoke injury and tended to give the impression of greater damage from the smoke than really existed.

April 15.—The barley plants mentioned above were found to have received no subsequent injury. The plants had made some growth and the injury previously noted was largely obliterated and would doubtless have been passed by the layman without notice. In the northern part of the property, which would be included in section 30—that is, adjoining the limits of Vallejo and near an old windmill—a field of young barley was carefully examined and found to be entirely free from smoke markings. The plants were 6 to 9 inches high. In certain areas the blades were yellowish from an excess of moisture in the soil. Numerous spots of brownish discolored tissue resulting from the growth of a fungus, Helminthosporium, were noted on the older blades. There were also numerous whitish markings caused by sucking insects. Barley that had already headed was found to be distinctly bleached from the hillside above the South Vallejo station to the southern limit of this variety. The bleaching was pronounced on affected blades, but only a small percentage of the blades was affected. It should be noted that this field of grain, extending southeastward from the limits of Vallejo, consisted of small patches of the three common varieties, oats, wheat, and barley interspersed. Passing southward from the South Vallejo station one encountered many of these plats of various ages and under different conditions. No discoloration was found on the oat blades and brome grass near the South Vallejo station, but approximately half way to

the south end of the field an occasional wild oat blade was found to be affected. The discoloration of the barley did not extend to the eastern edge of the field, but terminated perhaps half way across the area in an east and west direction. Broncho grass was discolored over the greater part of the area, but the markings were inconspicuous along the eastern border of the field.

May 2.—After the condition of the wheat on the property of witness No. 11 had been noted the wheat of this property near the residence was carefully examined and found to be somewhat thicker on the ground than the grain of witness No. 11. It was heading at an average height of approximately 3 feet. No indications of smelter-smoke injury were detected in this property along road No. 78.

May 4.—In the vicinity of the eucalyptus trees standing about the center of the place and along the road leading to the Dos Reis Cove a distinct oil odor was encountered. This odor was noticeable over a strip of land perhaps 20 rods wide. Farther south and beyond the mouth of the gulch that comes down through the grain field east of a small eucalyptus grove a distinct odor of sulphur dioxide was encountered, and was also noticeable over a stip of land a few rods wide. No evidence of injury to the grain was detected. Passing to the brow of the hill it was easily determined from the line of movement of the smoke that gas from the smelter was moving (or passing) to the point where the odor was detected.

A close examination of the barley was made to determine whether there had been any injury since the first discoloration had been noticed in the field. The plants were now over a foot in height and in what is called the "boot" stage. In only a few instances was discoloration found on the upper blades, and this was mainly in a small area on the northeast side of the knoll, about which this barley was growing. It was planned to revisit the spot in the near future to observe the effect of this fumigation.

May 8.—As indicated above, the area where the odor of gas was detected on May 4 was revisited and carefully examined for evidences of smoke injury. Not one blade of barley seemed to have been bleached or spotted. There were, however, evidences of an effect upon the wild-oat blades and broncho grass, both along the margin of the field and among the barley plants. Strongly bleached oat blades were found at the foot of the gulch above referred to, even beyond the northern edge of the tract of barley that had showed the smoke injury. A careful examination was made of a field of oats that immediately adjoins this barley on the north and west, and this was found to be entirely free from smoke markings. In making this observation the field was traversed from the border nearest the smelter to that farthest away. Next to this area on the west and north wheat was entirely free from discoloration. The wheat along

the road was well headed, but not beginning to ripen. In general, the stand was rather thin and the plants were uneven in height.

The pasture area was rather closely grazed before the 1st of May, and no distinct injury to native vegetation was observable more than a few rods from the bottom of the gulch through which a wagon road leads to the cove, and this was on leaves of filaree (*Erodium ciliatum* L' Her.).

The old orchard on this place seemed to have been neglected for a number of years and consisted mainly of almond trees. These were not examined, as they were not under cultivation, and apparently received no attention whatever.

The pear orchard, opposite the fumigation station—apparently a part of this property—was not really cultivated. The trees showed every evidence of neglect; many of them were stumps and others small clumps of brush resulting from the growth of suckers and water sprouts at the base of an older trunk which may have been broken off by stock. Blister mites were common on the foliage of these trees May 8. Several trees were rather well fruited. Barley had been sown in this orchard all around the trees. It was ripening on the last-named date, at a height of more than 3 feet. The heads were large and well filled.

Four or five head of stock were seen in the grain at various times, and in examining the field from one end to the other it was observed that these animals had a fairly well-beaten trail almost entire y around the area, and that they had tramped over and grazed over the entire area to some extent. The animals were young and perhaps permitted to take this advantage over the other stock kept on the more barren fields. Should complaints of low yield arise, this factor would be worth considering, though it was not an important element in the reduction of the yield.

The grain in general was uneven and "patchy"; weeds and native vegetation were abundant, especially several species of morning glory or bind weed (Convolvulus).

It should be noted that the fungus above mentioned, Helminthosporium, was common in all the barley plats and produced considerable spotting and discoloration, even hastening or causing the death of entire blades. Also that a rather large percentage of the blades showed a whitish discoloration or withering, in many instances due to a chlorotic condition associated with damp soil early in the season and a subsequent drying and cracking of the surface.

It will thus appear that the smoke injury that had been detected on this property was limited mainly to a small tract of barley in the extreme south end and to an occasional blade on the older barley in the western half of the grain field as far northwestward as the South

Vallejo station. Had there been plats of barley in the pasture land northeastward toward the property of witness No. 25 from the barley field that showed injury, it might have been possible to have traced the effect of the gas slightly farther in that direction.

To what extent the conditions of this season represent the average or normal conditions can not be determined, even from the statements of farmers. Wind records, etc., kept by others in the service of the commission, will supply this information.

CONDITIONS ON LAND OF WITNESS NO. 132.

The property belonging to witness No. 132 comprises 55 acres lying in section 32 or adjacent to Elliott Cove.

March 12, 1914.—In company with Dr. J. W. Blankinship I visited this place, noting especially the condition of native vegetation, shade trees, pines, roses, quinces, willows, and poplars. The pine trees showed a distinct yellowish discoloration, apparently due to water standing about the roots. The discoloration had no resemblance to smoke injury. The foliage of the eucalyptus trees was considerably spotted with white maculations which perhaps had been caused by fire about the base of the tree. However, this condition is commonly noted on eucalpytus trees in regions far removed from the possibility of smelter-smoke damage. It is brought on usually by winter changes or extreme and sudden summer heat. The latter cause is rarely operative, for the reason that this tree is resistant to drought and would not ordinarily be affected unless grown under conditions varying considerably from those of its natural habitat. Among the native species, wild roses, burr clover, and broncho grass (*Bromus maximus* Desf.) were carefully noted and found to be entirely free from smelter-smoke injury. The orchard adjoining the residence was observed to be in bad condition as to the shape and vitality of the trees. They were only partly in leaf at this time.

April 23, 1914.—On this date the property was visited in company with witness No. 11. The varieties above mentioned were found to be free from evidences of smelter-smoke injury, and it was also noted that the spring growth of the pines had obliterated their yellowish discoloration. The various varieties in the orchard were now in full leaf and found to have been considerably burned by the use of an improperly mixed spray. Apple leaves were falling freely and had brownish markings that might readily have been mistaken for smoke injury, and the same was true of the cherry leaves. In fact, the only foliage in this little orchard that was not so injured was that of a fig tree which the tenant stated had not been sprayed. He recognized the cause of this discoloration. The apple trees were badly infested with oyster-shell scale and green

aphis. The pear trees were considerably spotted by the spray and somewhat infested with the blister mite. A small amount of fruit had set on both apple and pear trees. The condition of the cherry trees was very poor; dead limbs were present; the trunks were gummy; the foliage showed marked burning by the spray; and the trees were ill-shapen and neglected.

Among these trees and extending somewhat beyond the limits of the small orchard barley had grown to a height of 2 feet or more since the former visit. The culms were heading and very badly infested with lice. The tenant had not noticed this, and when it was brought to his attention he stated that he had never seen anything like it before. There was also a distinct bleaching, particularly of the terminal and subterminal blades, caused by smelter smoke (Pl. XXXV). This condition was not sufficiently prominent to attract the attention of the tenant or of witness No. 11, both of whom walked through the field looking at the infestation of aphis. In many instances the blades were almost entirely bleached, the bleached blades being somewhat scattered about. The amount of damage, if any, was entirely inconsiderable, and it was evident from the condition of the lower blades that there had been no damaging visitation of smoke prior to the fumigation that had caused this bleaching, unless it had been when the grain was very young. Broncho grass (*Bromus maximus* Desf.) was slightly affected, but no other vegetation of any sort could be found that showed smoke injury. Younger barley on the low hill between the house of witness No. 132 and Elliott Cove proper was entirely free from smelter-smoke bleaching or spotting.

May 4, 1914.—Conditions mentioned as existing on April 23 as to insect pests, injury from spraying, etc., were still present. In reference to the bleaching of the barley blades there appeared to have been either a revisitation of the smoke or there had been no change in the blades previously bleached. The bleaching did not seem to be more extensive but occurred on the latest developed blades. Other susceptible vegetation, both native and cultivated, about the place was examined closely and found to be uninjured.

In this connection it may be mentioned that a few barley blades on the hill between Glen Cove and Elliott Cove in what was thought to be property of the Pacific States Trading Co., and also in the property of witness No. 49, adjoining Glen Cove, were found slightly bleached, apparently by smelter smoke. Only a few affected blades were found, and in such instances it is by no means certain that the discoloration was caused by smelter smoke, as it is possible to find, beyond the possibility of smoke injury, isolated specimens of various sorts of vegetation which can not readily be distinguished from specimens that have suffered smoke injury. However, broncho

grass, at the two points just mentioned, was affected similarly, which increases the probability of smoke injury. No other sorts of vegetation were found to be affected at these points.

The remaining tracts belonging to witness No. 132 were not examined and no reports can be made on the conditions that may have existed thereon. The main hayfield and also the barley above mentioned showed considerable spotting, due to the fungus Helminthosporium, but this is generally an unimportant factor in the reduction in yield of hay and grain. Some of the most thrifty and vigorous looking grain is often most seriously attacked by this fungus.

CONDITIONS IN THE VICINITY OF GLEN COVE.

Conditions in the vicinity of Glen Cove are described below.

March 12, 1914.—In company with Dr. J. W. Blankinship I drove down from the Carquinez cemetery to the place owned by witness No. 8, and noted that eucalyptus trees about the house showed pronounced whitish discoloration on both lower and upper leaves, such as is described elsewhere. Blackberries, acacias, willows, and a few garden varieties in the dooryard were found and noted to be free from smoke discoloration. The orchard of apples, apricots, peaches, plums, cherries, and almonds was not examined at this time. Only a few of the trees were in leaf.

Along the road the native vegetation, particularly that known to be most susceptible to smoke injury, was noted at various points and found to be in normal condition. Some distance down the gulch below the residence of witness No. 8 a field of barley, just up, was found in normal condition. The ownership of this barley was not determined. A strip of land in the bottom of the gulch was prepared for seeding but was still too wet to be sown.

Near a gateway at the top of the hill between Elliott Cove and Glen Cove wheat south of and oats on the north side of the road were examined and found to be entirely free from smoke markings, though the wheat showed noticeable yellowish discoloration of the lowermost blades. Barley plants in the oat field were also free from smoke markings. Fungous spots were present on both oat and barley blades. Between this point and Glen Cove native vegetation was examined and found in normal condition. In Glen Cove quite an assortment of plants, including trees, shrubbery, and herbage, showed no smoke markings. The herbage included a number of garden varieties that are particularly susceptible to smoke injury.

April 23, 1914.—The garden, shrubbery, and trees about the Glen Cove property were carefully examined and found to be free from smoke markings. Particular note was taken of a rather large bed of sunflowers near this garden, which were found to be green and

thrifty in appearance. The wheat on the land of the Pacific States Trading Co. showed more yellowish discoloration of the lower blades and a condition corresponding with that described as existing on the place of witness No. 11. The stand was quite thin and there were few culms per plant. At the top of the hill where the road passes through a gate to the Fish house, in Elliott Cove, barley and oat plants were carefully examined and found to be in normal condition save for the presence of fungous spots. Barley in the bottom of this gulch was a few inches in height, and though the ground was normally very moist from seepage, the area had been irrigated. Barley on the west slope of this gulch was in the boot stage and free from smoke injury.

May 4, 1914.—The various species of vegetation in Glen Cove which have been mentioned above were found to be free from evidences of smoke injury and other serious pathologic conditions in general.

A careful examination was made of the orchard of witness No. 5 and the following conditions noted: Almond trees were not especially thrifty; fruit was rather sparse; and black scales were present. Some of the leaves showed the presence of the shot-hole disease. The plum trees were in fair foliage, but somewhat infested with lice and badly infested with green, leaf-rolling, tortricid larvæ related to the codling moth worm. Fruit was quite abundant. Apricot trees were free from pathologic conditions and sparsely fruited. Apple trees showed a considerable infestation of oyster-shell scale. Woolly aphis was also noted. The pears were somewhat infested with blister mite, and some leaf rollers were present. In a garden adjoining beans, peas, beets, turnips, onions, and lettuce were found in normal condition. Wild oats and various sorts of grasses besides several species of shade trees were also in good condition.

On a hill between the two coves and also on the place of witness No. 49 a few barley blades were found showing discoloration that seemed to have been caused by smelter smoke. Considerable searching was required to find these blades. Helminthosporium spots were abundant in both places.

On the place of witness No. 8 an examination was made of the orchard and ornamental plants about the residence. Apples were found to be badly infested with woolly aphis, so much so that it was rather remarkable that the trees were living. A few of the trees were dead. The apricot trees were in fair condition. The peach trees showed many spots caused by the shot-hole disease. Lice were very abundant on the plums. The cherry trees were normal. One chestnut tree showed some burning of the foliage and cracking of the bark, presumably due to the location of the tree against the side of a building. Almond and pear trees were in fair condition, displaying no special pathologic conditions deserving mention. Acacias, wil-

lows, blackberries, roses, grapes, parsley, and grasses were noted and found to be in normal condition, save that the grapes were not growing rapidly. Barley on the hill east of the residence and wild oats, native grasses, etc., along the road were normal.

The barley field in Elliott Cove showed no smoke markings, nor were any markings of this sort to be found in the various species of grass and native vegetation.

CONDITIONS ON THE PLACE OF WITNESS NO. 11.

Conditions on the place of witness No. 11, comprising 469 acres lying in sections 28 and 33, are described below:

March 12, 1914.—This property was entered from the Glen Cove side and traversed to the outlet on the eastern side, but no careful examination was made of the various crops. The greater part of the area adjoining Glen Cove was not being cropped but had produced a rather abundant growth of wild oats, grasses, and weeds, and was being pastured by sheep. None of the species, either native or cultivated, in the area showed smoke markings. A plat of barley above the residence of witness No. 11 and near the cable anchor showed a pronounced yellowish streak in its central part, due to excessive moisture in the soil. The grain was much shorter in this strip than elsewhere. Witness No. 11 was cultivating the orchard, but we did not tarry to examine the trees as it was too early in the season to procure much data from orchard varieties and too late in the day to make an investigation. Between the residence and the main road we noted the condition of the pasture and of the wheat. The latter was thin on the ground and showed a slight yellowish discoloration of the lower blades. The pasture looked quite well. Various sorts of vegetation that normally show a susceptibility to smoke injury were examined along the road and found to be free from smoke markings.

March 18, 1914.—The northeastern extreme of the wheat field—that is, the part lying along the main road—was examined more carefully than on the former date and the plants were found to be 10 inches high. The blades were arching slightly and the stand was rather poor. Oat blades in the area were carefully examined and found to be in normal condition.

April 7, 1914.—Wheat at the point mentioned on the former date was somewhat over a foot in height; the upper blades were wide and showed good color. They were considerably arched but the lower blades were quite yellowish, and those on the middle zone of each culm showed a distinct mottling of fine yellowish spots, a condition that seems to be common to wheat throughout California at a certain stage of its development. The exact cause is not known to me nor to other pathologists with whom I have talked.

April 23, 1914.—As I was about to examine the orchard near the residence witness No. 11 alleged that there was nothing to be seen now in the orchard, that there was no smoke injury until later in the season when winds become more constant from the west; he requested me to drive back to the wheat field and note conditions. The wheat was then in the boot stage. Witness No. 11 complained of the thinness of the stand and the yellowish discoloration of the lower blades. He did not positively attribute these conditions to smelter-smoke injury but stated that there was some poison or other harmful substance in the soil which prevented the normal development of the crop. He stated that this had been well sown and that the land had not been cropped during the preceding three years. He further alleged that under such circumstances the plants should be so high and thrifty that it would be difficult to walk through the grain. He thought that he would not harvest as much as half a crop.

April 25, 1914.—In connection with allegations of witness No. 11 regarding his wheat, an average plant was taken on this date from the northern limits of the place and carefully described. The following notes indicate conditions: One culm, 56½ inches from the tip of its terminal blade to the ground. Terminal blade, 12 inches in length; subterminal, 15 inches long by three-quarters of an inch wide. The next blade lower was 12¾ inches long, the next 9½, and the next 8 inches. The last one was somewhat yellowish, though it still had considerable healthy tissue. The upper blades were arched and showed good color. A second culm was 16 inches from the tip of its terminal blade to the ground; a third culm was 13½ inches in length; four other culms were weak and with much dead tissue, and one culm was entirely dead. I did not at the time know the cause of the preeminence of the one culm and the dwarfing of the others in this particular plant, and consequently the thinness of the stand, but fancied that the explanation was associated with climatic conditions and the conditions of the soil that prevailed earlier in the season. Witness No. 11 was advised that the wheat had been carefully observed since the 12th of March, but that back of that time I had no information as to what conditions may have existed in this field. The specimen was subsequently studied in the laboratory and was found to be badly infested with Hessian fly.

May 2, 1914.—The wheat was heading at a height of 2 to 5 feet. The tallest blades were usually higher on the slope and the shorter ones on the lower areas. Witness inquired as to my further movements, and upon learning that I was going toward Glen Cove suggested that he accompany me. It thus happened that his orchard was not examined on that date.

May 4, 1914.—In the orchard I noted that four or five peach trees were dead and that others in little better condition were badly affected with shot-hole disease. The soil was in poor condition and in a poor state of cultivation. One apple tree showed a pronounced discoloration which suggested that a fire had been kindled too near the tree. No evidence of such a fire could be found to explain the phenomenon. Witness returned from Benicia before the examination was completed and stated that he did not know what was the matter with the apple tree, but that it could not be suffering from smelter smoke, else other trees would be affected similarly. The two trees adjoining showed slight discoloration. These trees were badly infested with green aphis and considerably infested with leaf-rolling larvae related to the codling moth. The pear trees were badly infested with blister mite and with the same kind of leaf-rolling larvae found in the apple trees. Most of the trees were small. Some fruit had set. The larger trees had a fair crop of fruit. The apricot and cherry trees were in normal condition save that there was little fruit present. The plum trees were badly infested with aphis. A few other insects were noted, but these were doing no considerable damage.

CONDITIONS ON THE PLACE OF WITNESS NO. 32.

Conditions on the place of witness No. 32, comprising 58.42 acres, lying in section 28, were investigated, with the results presented below:

March 12, 1914.—Barley in a field immediately adjoining the residence and north of the same was beginning to head at a height of 14 to 16 inches. Just north of this area a second small field of barley was only a few inches in height. About the residence a considerable variety of ornamental plants, date palms, roses, pomegranates, oranges, periwinkle, etc., were observed. The pomegranates had not yet developed the season's leaves and the orange trees were in bad condition, suggestive of neglect and drought. Peas just south of these ornamentals were beginning to flower and appeared normal and healthy. Still farther south, in a swampy area, some old fruit trees, especially pears, were observed and appeared to be in poor condition. On the knoll farther to the south an old orchard of plum trees with an almond border showed the same neglect and lack of cultivation. The almond trees were rather well covered with foliage, but had not been pruned for many years and were bushy, besides displaying a great many dead twigs. No indications of smelter-smoke injury were detected on this property.

March 16, 1914.—The young field of barley referred to on the former date was 6 to 8 inches high and less uniform throughout

than when first noted. No discoloration of any sort was noted save some blade spots caused by Helminthosporium. Pear and plum trees were in bloom. Native species of various sorts showed no smoke markings.

April 7, 1914.—The northernmost barley field was 12 to 18 inches high and coming into the boot stage. The plants were not so nearly uniform in height as formerly, but more even than in many other places. No mottling or discoloring was noted save a few of the fungous spots above mentioned. The older field of barley just south of this showed more discoloration by the fungus and showed an occasional blade mottled as described in report on the place of witness No. 12. The culms were 3 to 3½ feet in height.

April 23, 1914.—The northernmost barley field was now heading. The plat just south of this was beginning to mature. No evidence of smoke injury was detected on any of the native or cultivated species.

April 25, 1914.—Back of the residence a rather large garden, which was seemingly attended by Italians, was carefully examined and the following conditions noted: Potatoes were several inches high, but very uneven, some of the plants coming barely above the ground, and there were many vacant spaces. There was some slight discoloration of the leaves, produced by natural agencies such as insects, fungus diseases, and climatic conditions. This discoloration was insufficient, however, to attract attention. Corn was only a few inches high and in medium to poor condition; that is, the plants were not thrifty. Beans showed considerable yellowish tissue and were in a chlorotic condition. The beets were normal though rather small for the apparent age of the plants. The horse beans were tall and flowering but with considerable dark-brown discoloration of the foliage, particularly of the lower leaves, possibly due to fungous disease. All the horse beans noted in the region showed this condition. Carrots, cabbage, onions, and turnips were in fair condition with no discoloration. Lettuce showed a considerable wilting and discoloring due to the fungus Botrytis. The leaves and the bark of the plum and the prune trees were literally coated with prune aphis. Apples, almonds, figs, walnuts, and ornamentals were in normal condition save that they were uncared for, and the almonds displayed considerable dead wood. The figs showed some deforming of the leaves, and there were scale insects present on the apples and almonds. The peach trees were in poor condition, displaying what is known as "die-back," perhaps due more to neglect than to any other cause.

May 2, 1914.—The barley just north of the house lot was cut. The northernmost field was beginning to ripen. There was no evidence of smelter-smoke injury on the native or cultivated species.

Shade trees on the swampy area and adjacent thereto were in fine foliage.

CONDITIONS ON THE PLACE OF WITNESS NO. 12.

Conditions on the place of witness No. 12, comprising 779.16 acres, lying mainly in sections 22 and 27, were as outlined below:

At the time of the first visit to this property, March 12, 1914, in company with Dr. J. W. Blankenship, it was noted that the barley southwest of the road near the city limits of Benicia was in the boot stage. The plants were very uneven and generally thin on the ground. No discoloration of the blades was present save some spotting caused by the fungus Helminthosporium and the normal weathering of the oldest blades, which at this time were close to or in contact with the ground. The part of the field farthest southeastward was in the poorest condition. Farther up the road northwestward the plants were larger and the stand was generally better. On the hillside east of the road and immediately adjoining the city limits of Benicia, the barley was found to be very much taller and more thrifty close to the fence than a few feet away from the fence. The stand was also very much better and the color of the plants was more normal. In addition to the barley there was a considerable growth of wild oats, grass, and native vegetation close to the fence. This condition, that is, the narrow strip of thrifty grain along the fence, is quite common in the region, particularly on hill slopes, as the contour of the country necessitates plowing "round and round," thus piling up along the fence a stratum of surface soil more rich in humus than the soil in the open field. To be sure, there is also a washing from the higher levels and a consequent denuding and impoverishing of the higher lying soil to the advantage of the strip at the border of the field or along the fence where a slight embankment is formed by the method of plowing above cited.

In this connection it is well to note that while the less thrifty-looking grain is pointed out by farmers as evidence of smelter-smoke injury, the condition just described seems to indicate very definitely that the less thrifty grain has not been injured either by poison in the soil (a common belief among the farmers) or by atmospheric agencies, but its condition is due to the repeated cropping of the land to grain varieties, and probably also to the leaching or washing of the soil by rainfall. If poison were present in the surface soil, as imagined by the farmers, it would be accumulated at the base of the field and its effects there should be more noticeable than where the thinner stratum lies. No such strip of thrifty grain is observable on the upper levels, at least there is much less contrast between the grain of the upper border and that of the main part of the field.

On the slope of the hill near the city limits of Benicia barley blades were found to show whitish discoloration commonly somewhat mot-

tled in character and occurring on one blade, usually the second, third, or fourth blade from the last developed; more frequently than otherwise on the third blade from the terminal. This had somewhat the appearance of smoke injury, but was not typical or characteristic. A similar condition has been noted in another smoke zone under certain combinations of weather, soil, and stage of maturity. If it is due to smoke injury, it is not the generally-recognized type. It must be added that quite similar effects were produced during the summer by Mr. Wells in the fumigation tests. The amount of discoloration was generally small and unimportant. Many of the plants were entirely free from discoloration, and usually the affected plants retained a good proportion of green tissue. Farther northwestward along the slope a large tract seemed to have been spring-plowed, but not sown, as the grain plants were few and backward in development. Back of this strip the hillside was devoted to the production of wild-oat hay. It is probable that both the wild-oat hay and the barley above described were purely volunteer; that no seed was sown after the harvesting of last season's crops. Under these conditions clay soil becomes hard and baked at the surface, does not readily permit the penetration of rainwater, but may become very soft at the surface, even to the extent of "running together." Grain roots in such soil are often shallow and easily injured by the cracking and drying out of the surface layer.

About the residence of witness No. 13 eucalyptus and cypress trees showed discoloration. The cypress trees were apparently suffering from conditions that prevailed last season and even the season preceding, to judge from other known facts relative to this species and its occurrence in the bay region. The eucalyptus trees showed the same whitish markings described as occurring on the place of witness No. 132.

About the residence of witness No. 12 a small orchard of almond, apple, peach, apricot, and cherry trees had been cultivated and seemed in good condition. The almond trees were fairly well clothed with foliage and blossoms were appearing on the peach and apricot varieties. Garden peas had grown to a height of several inches and were in normal condition. The barley just northwest of this residence was in much the same condition as that farther east, save that it did not show the whitish discoloration. Native species, including burr clover, buckthorn (Amsinckia), Napa thistle, black mustard, and chickweeds (*Stellaria media* Cyrill. and *Cerastium viscosum* L.), wild oats, and native grasses, both in the hayfield and along the border, showed no discoloration resembling smoke injury.

March 16, 1914.—The barley in the main field, where discoloration was noted on the 12th, was at this time about a foot in height and had developed the last blade, though this was not fully expanded in all cases. Whitish mottling was still noted on the third blade from

the last. It should have been noted earlier that the barley on the slope where discoloration was noted was considerably higher and better in appearance than the barley growing southwest or west of the road, where no discoloration was found. Wild oats and a rather large list of native species, including those mentioned above and a few other varieties, were still free from smelter-smoke discoloration. The lower blades of the wild-oat plants along the margin of this field showed considerable brownish or reddish discoloration, due to age and weathering, and the younger blades were very commonly marked with purplish spots produced by Helminthosporium. Heads were beginning to appear on the west side of the road farther from the Benicia city limits, though the culms were still rather short. No whitish markings were found anywhere in this plat west of the road. Peas mentioned in the former report were in bloom and free from abnormal conditions. The peach and apricot trees were beginning to unfold their leaves and were quite showy with blossoms. The hayfield of wild oats showed no discoloration save that described in connection with the taller plants along the margin of the field. Wheat plants scattered about the fields on the east side of the road showed more or less yellowish discoloration, not in anywise resembling smoke injury. The barley plants showed considerable more discoloration, particularly of the lower leaves, caused by Helminthosporium.

April 7, 1914.—The whitish mottling of the barley blades formerly noted was still present and in about the same abundance. More discoloration had resulted from the fungus Helminthosporium, and the grain was heading.

Conditions were much the same west of the road as noted formerly, save that the grain was more advanced and there was more yellowish discoloration of the lower blades. The plat of barley in the western extreme of this place, adjoining the tract owned by witness No. 95, was 14 inches in height and fairly thrifty in appearance.

April 23, 1914.—The barley, west of the road in particular, was beginning to ripen. All of the blades showed more or less yellowish discoloration. The height was fair for volunteer grain, and the heads were medium to small. The heads were larger on the higher land and smaller on the lower land. The orchard and peas about the residence of witness No. 12 were in fine condition.

April 25, 1914.—There were no appreciable changes in conditions since the former report.

May 2, 1914.—The large field of wild-oat hay on the hillside east of the road was mostly cut and raked. The barley west of the road was ripening. Native species showed no evidence of smoke injury though many varieties had begun to dry from drought and maturity, especially burr clover and filaree.

May 4, 1914.—Conditions were unchanged except for the normal maturing and advancing of the varieties that were still growing, both of the cultivated and native species.

May 8, 1914.—Barley east of the road was sufficiently ripe to be cut for hay; that west of the road was already partly mowed.

CONDITIONS ON THE PROPERTIES OF OTHER PERSONS.

Conditions were also observed on the properties of the following: Witness No. 25, 135.43 acres; witness No. 4, 220 acres; witness No. 33, 50 acres; witness No. 34, 447 acres; and witness No. 95, 3.56 acres.

March 12, 1914.—Volunteer grain and native vegetation on the place of witness No. 33 were observed along the road. The grain was rather short, though considerably higher at the margin of the field than elsewhere. Otherwise the vegetation was in normal condition.

On the place of witness No. 25 an old orchard of pear trees with barley sown between the rows was noted. The barley was higher than any other in the region. The pear trees were beginning to flower. No discoloration was found resembling smoke injury.

Barley north of the road was somewhat higher than that in the orchard and considerably infected with Helminthosporium. A luxuriant growth of filaree, mustard, chickweed, burr clover, red maids, and other native species adjoining this plat of barley was found to be in normal condition. About the residence lemon, orange, and loquat trees were in normal condition save that the foliage of the citrous varieties was somewhat thin.

Two or three trees in a cypress hedge showed some discoloration. These trees were apparently dying, either from root troubles or from previous climatic conditions. Volunteer grain farther eastward was rather short, but showed no special conditions deserving of mention. A large area south of the road was not under cultivation, apparently intended for pasturage.

On the property of witness No. 34 an abandoned orchard of several of the common varieties was found to be half dead. It had apparently been browsed by stock. No evidence of smoke injury was to be found on the native vegetation on this place.

Opposite the place of witness No. 34 in the cemetery a large number of cypress trees had died and others were in very poor condition. The cause of this was not apparent and the reason can only be suggested in view of the poor condition of shade trees throughout the region caused by previous dry seasons. It seemed also that the soil at this point was rather shallow, being closely underlain by rock.

On the property of witness No. 4 volunteer grain occupied the narrow strip of land north of the road. This was rather short and thin on the ground. Some volunteer grain south of the road was in much

the same condition. About the residence ornamental trees and a few old fruit trees showed no pathologic conditions, excepting those resulting from neglect.

On the place of witness No. 95 barley and alfalfa plants besides native species were noted. The barley was somewhat less than a foot in height and showed a rather serious infection of Helminthosporium. The stand was quite uniform. Acacias were in normal condition.

March 16, 1914.—On the place of witness No. 33 volunteer grain was measured and found to be not over 6 inches in height, though 14 inches along the fence. The height of the plants was somewhat variable in the open field. No pathologic conditions save the presence of fungous spots and thrips markings were present.

On the place of witness No. 25 barley north of the road was 1 to 3 feet high and showed no discoloration except of the blades at the base of the plants. An occasional blade was found which showed the white mottling described in the report on the place of witness No. 12. This blade was usually the fourth from the last developed. Helminthosporium was especially abundant. Some mildew was noted on the wild oats, and thrips markings were rather common. The native species referred to on the former date were in normal condition. Barley south of the road varied considerably in height, from 1 to 3 feet. Volunteer grain in the eastern portion of the place was somewhat better than on the place of witness No. 33.

On the property of witness No. 4 it was noted that stock had been grazing the volunteer grain north of the road. The plants were mainly barley near the barn and mainly wild oats farther up the hill. Mustard was very abundant in the barley. The old orchard trees back of the residence were in leaf. No examination was made. Burr clover, filaree, chickweed, etc., were found to be free from smoke markings.

Barley on the place of witness No. 95 was found to be about 8 inches tall. Some of the plants were small and weak and the blades showed a streaking suggestive of a bacterial disease, but caused by the fungus *Helminthosporium graminum.* Another species of Helminthosporium was abundant.

March 18, 1914.—Conditions on the places named on the 16th were much the same, except that vegetation was slightly more advanced.

April 7, 1914.—Volunteer grain on the place of witness No. 33 was now about 12 inches in height. No important pathologic conditions were noted.

On the place of witness No. 25 barley north of the road was badly infected with Helminthosporium. Many dead blades were

noted near the base of the culms, and these were commonly marked by spots of saprophytic fungi. The pear trees were past the blossom stage and fruit was setting. A small plat of barley had been cut for green feed.

Volunteer grain both north and south of the road in the western part of the place of witness No. 4 was heading at a height of about a foot. The barley north of the road near the barn was considerably grazed and mustard plants were very prominent. Thrips markings were especially abundant on the wild oats.

On the place of witness No. 95 barley was 14 inches or more in height and in the boot stage. The conditions mentioned on the preceding date were still present and in about the same degree. During the remainder of the investigation these places were noted at rather frequent intervals and at no time was smoke injury found on any sort of vegetation along the road to the fumigation station from Benecia. The main pathologic condition that was later noted was the almost total defoliation of five or six pear trees in the orchard of witness No. 25 by the greenish, tortricid, leaf-rolling larvæ mentioned in connection with the orchard of witness No. 5. This condition was observed on the 11th of April. In May these worms were found pupating.

May 2, 1914.—The barley in the orchard of witness No. 25 was cut and being raked. One blade in a strip which had been missed by the mower showed markings which closely resembled smoke injury.

Oats on the property of witness No. 4, south of the old orchard, were found to show considerable yellowish and reddish discoloration of the blades. The plants were rather short and not as thrifty as they should have been at that season of the year. The sowing had doubtless been done late. Wheat in the extreme western part of this place and north of the road was heading at a height of about 2 feet.

CONDITIONS IN THE WESTERN PART OF BENICIA.

The westernmost part of the limits of Benicia consisted of barley fields, a large part of which was said to belong to the Montgomery estate.

On March 12, 1914, this barley was in essentially the same condition as that on the place of witness No. 12 immediately adjoining. The mottled discoloration of the blades was identically the same and quite generally distributed over the hilly area. Near the city limits a small garden and house lot were observed from the road. The almond trees over the fence showed a discoloration of the foliage generally characterized by straight lines and bands which had no resemblance to smoke injury. These trees were doubtless subjected to a considerable variation in the water supply, and the discoloration

may well have been due to that factor. Bramble foliage was carefully noted and found to be free from smoke markings. Grass and native species showed no injury.

Somewhat farther from the city limits a field of volunteer grain was examined and found to be entirely free from evidences of smoke injury. This field was directly opposite the new residence owned by witness No. 67. Slightly farther eastward a field of barley was noted and seemed to be in normal condition. Still farther eastward a field of wild-oat hay on the north side of the road, belonging to witness No. 76, whose residence is on K Street, was in fine condition, save that the blades showed fungous spotting and a considerable infection of mildew. The lower blades were often yellowish or entirely dead from age and weathering. Along the road a luxuriant growth of black mustard and burr clover was found to be free from smoke markings.

A large garden lying some distance up a gulch from the road was closely examined and found to be in good condition, free from smoke markings and other pathologic conditions, save a dark-brown discoloration of the leaves of the horse beans, as cited elsewhere.

March 16, 1914.—The volunteer oats on the lot of witness No. 76 were heading. From two to four blades only were entirely green. The plants were thick on the ground and the lower blades were commonly brownish or yellowish. Some whitish marginal discoloration was noted on subterminal blades. Helminthosporium spots were numerous and thrips were found producing a characteristic spotting of the blades. Black mustard, burr clover, filaree, gum plants, and other native species showed no evidence of smoke injury.

On the Montgomery estate it was noted that the barley northeast of the road was very uneven, being from 1 to 3 feet in height. The subterminal blade was expanded or unfolding on most of the culms. The whitish mottling referred to above was still in evidence. A few wild-oat plants in the barley showed a marginal whitish discoloration not typical of or closely resembling smoke injury. Chickweed and other native species were in normal condition.

The volunteer grain opposite the residence of witness No. 121 was being pastured. Four blades were green, though the subterminal ones showed some brownish streaking or spotting. Burr clover, both gray (wild rutabaga) and black mustard, chickweed, Napa thistle, morning-glory, filaree, fennel, and the native grasses showed no discoloration.

March 23, 1914.—About station 1 filaree showed a very brownish discoloration which was apparently caused by smelter smoke. Burr clover was entirely unaffected. Mallow, in addition to the normal discoloration and injury produced by rust, showed characteristic smoke markings and broncho grass (*Bromus maximus* Desf.) was slightly

affected. It was rather unreasonable to suppose that this condition was caused by a visitation of smelter smoke, since burr clover and other very sensitive plants were unaffected. Nevertheless there are a number of inexplicable matters in connection with smoke investigations which would lead one to overlook these apparently contradictory conditions. Wheat immediately adjoining the area on which these discolored species grew was in normal condition.

March 30, 1914.—Just eastward across the gulch from station 1 a plat of wild oats was carefully examined and found to be in good condition. The plants were tall and thrifty and showed no evidence whatever of smoke injury, except that the fourth blade from the last developed was somewhat bleached at the end. This bleaching was, however, so old and so greatly influenced by weather conditions that it was impossible to determine what had been the original cause.

April 7, 1914.—The whitish mottling of the barley blades on the Montgomery estate was still conspicuous and affecting the second and third blades from the last developed. Smut was abundant in the heads. No evidence of smoke injury was found on any of the places cited above, save that conditions about station 1 were only slightly changed by a subsequent growth of the species involved.

April 11, 1914.—Witness No. 133, who resides in the western part of Benicia adjoining witness No. 76, complained bitterly of the "total destruction" of the peach orchard and other crops on his small lot which lies between the road and the water front. An examination was made of the property and it was found that the most sensitive species were apparently in normal condition and entirely free from smoke markings. Apricots—among the most resistant species to smelter fumes—were in bad condition, apparently from a root trouble or sour sap. The trees in question were merely seedlings and small. Fig trees were found to be losing their fruit freely and to show a peculiar deforming of the foliage, both of which witness No. 133 considered due to smelter injury. The cause of this was not determined. Peach trees were densely covered with black aphis. Apple trees showed no discoloration. Lettuce, roses, and a large list of ornamentals were carefully examined and found to be free from smoke markings.

Various other points in the western part of Benicia were visited and all sorts of vegetation examined, but no smoke injury was detected.

April 23, 1914.—Opposite the residence of witness No. 121 in the western part of Benicia barley plants were 14 to 18 inches high and in the boot stage. The lower blades were generally yellow or dead. The soil, which was heavy clay, was badly cracked and drying out.

On the Montgomery estate barley was ripening and the blades were practically all yellowish.

An examination was made of a garden on the lot on K Street of witness No. 76 and the following conditions noted: Beans, beets, peas, lettuce, cauliflower, carrots, corn, pears, and peaches were all in normal condition. The potato vines were rather uneven and the leaves showed some brownish spotting. The lettuce was mature and many of the plants were apparently infected with Botrytis. The oat plat was half cut and a liberal quantity of hay was being harvested.

April 25, 1914.—A careful examination was made of a garden near the western limits of Benicia and the following conditions noted: Peas, beans, beets (both red and white), lettuce, carrots, squash, blackberries, almonds, lambs' quarter, broncho grass, dock, and certain other native species were found to be free from smoke markings. Some leaf-hopper injury was noted on squash leaves. The almond trees showed the discoloration above described. A woman residing on this lot complained considerably of smoke injury and of an "unbearable odor which was frequently present." When asked to indicate what varieties in the garden were affected she replied that nothing seemed to grow as it should.

The oat plants on the lot of witness No. 134 were examined and found to be free from smoke markings. The plants had grown to a considerable height and were in every way thrifty. Native vegetation was found to be in normal condition.

May 2, 1914.—The oat plants on the lot of witness No. 134 on J Street were beginning to ripen at a height of 5 or 6 feet.

About station 1 wheat and grass were in normal condition, though the wheat showed an abundance of yellowish discoloration, particularly the lower blades.

Potato leaves on the lot of witness No. 76 showed considerable brownish spotting and the vines were rather small. Witness complained that the potatoes were "knocked out" as soon as the wind began to come from the direction of Selby. The ground was very dry and the potatoes were being dug. Barley opposite the residence of witness No. 121 was beginning to head. Wild-oat plants were rather short and with a considerable yellowish discoloration of the lower blades.

No smoke injury was detected within the city limits.

As the lot of witness No. 134 on J Street, just across the gulch from station 1, seemed in the line of frequent winds from the Selby smelter, and as these plants had, earlier in the season, shown a whitish discoloration of the blade ends, it was thought desirable to take some of these plants and describe them accurately. The following description pertains to one of the larger plants, but a specimen which was little above the average: Height from ground to end of longest blade, 5½ feet; length of terminal blade, 16½ inches; subterminal blade, 21½

inches; next lower, 19½ inches; next lower, 17¾ inches; next lower, 16 inches; width of terminal blade, 1⅜ inches. The terminal and subterminal blades were all green save for a slight marring at the ends. The next blade was about half green—not a bright green. The next blade was considerably more yellow, the next one quite yellow, and all below this were dead. The head was entirely green, and the number of double grains was 150. These measurements are given to show that wild oats, though very sensitive to smelter fumes, growing at a point where sulphur dioxide from the smelter was probably carried frequently, grew to rather unusual or abnormal height, and were thus apparently unaffected by the strength of sulphur dioxide that reached the point.

CONDITIONS ALONG THE ROAD LEADING NORTHEAST FROM BENICIA.

Conditions along the road leading from Benicia northeast to Vallejo were as follows:

March 12, 1914.—In company with Dr. J. W. Blankinship I made a trip along this road to skirt, so to speak, the limit of alleged smoke damage from the Selby smelter.

East of Benicia, on the arsenal grounds, cypress, eucalyptus, pines, and even pepper trees showed considerable discoloration. There were many dead trees of the first three species. These conditions were probably due to the dry seasons of the last two or three years. Native species, which are known to be susceptible to smoke injury, were noted en route from the principal street in Benicia to the arsenal grounds and found to be free from smoke markings.

Before reaching the place of witness No. 17 we passed a few old orchards in bad condition, notably an olive orchard and a few almond orchards, and these were free from smoke markings. An old vineyard west of this road was pointed out by Dr. Blankinship as a case in which smoke damage was alleged. This vineyard had not begun to develop the season's shoots, and nothing could be determined with reference to its condition.

On the place of witness No. 17 the orchard was in an abandoned condition and consisted of a few trees back of the house and a few in a pasture lot. About the residence a cypress tree was observed with considerable discoloration, evidently resulting from the death of limbs and twigs. One pine tree was dead and another was in good condition. Oats just beyond the house lot were several inches high and the area was quite weedy. The remainder of an old vineyard in a pasture area, apparently abandoned, was observed.

Across the road, on property which appeared to belong to the heirs of witness No. 35, wild oats, with scattering plants of other grain intermixed, were a few inches in height and in good condition, save for

the presence of fungous spots and some yellowish discoloration of the barley blades. Opposite the residence of witness No. 16 farther up the road a plat of oats was quite thin on the ground and only a few inches in height. Native species along the fence were in good condition and free from discoloration.

On the place of witness No. 18 a rather long row of almond trees extended along the road and back some distance along a division fence. These trees were in leaf and some nuts had formed. The trees were rather small and in a somewhat neglected condition, especially in a low area near the corner of the border. An occasional leaf showed a spot of discoloration usually extending across the outer end. An avenue of peppers along the private roadway showed some discoloration. The trees were rather small and stunted in the central portion of this avenue but larger at each end. The family orchard and ornamental plants were noted, but not closely examined.

On the place of witness No. 19, at an abrupt turn in the road a rather large number of eucalyptus, cypress, and oak trees were observed. Some of the cypress trees were dying. The oaks were rather gnarly, largely from insect galls. An almond orchard on the hill adjoining the residence was in leaf. Certain pear trees in a low area near the road were in bloom. Native species were observed and found to be in normal condition. Barley opposite the residence of witness No. 36 looked well and was several inches in height.

The property of witness No. 36 seemed to be a stopping place merely as there was nothing under cultivation in the small inclosure. The area consisted of a rather low basin and a steep hillside. A remnant of a vineyard occupied the highest part of the slope. A few fig, pear, and quince trees were standing about the house in an abandoned condition.

One of the most striking features of the property of witness No. 16 was the dense growth of thistle on the sides of the gulch about the residence of witness No. 36. Eucalyptus trees around the house showed some whitish spots such as described on other places. The younger trees with the broad leaves were commonly free from this discoloration. A young orchard of various sorts, peaches, cherries, figs, and quinces, and a rather large vineyard were noted. North of the residence a plat of oats was several inches in height and fairly uniform. The stand was good. Mustard was abundant in spots. No discoloration was noted on any of the cultivated or native species.

On the place of witness No. 29 a field of barley was noted north of the road on heavy adobe soil. The plants were several inches high and in normal condition. Beyond this on the hills what appeared to be an oat field was observed only from a distance. About the residence cypress, locust, pepper, and eucalyptus trees were standing,

the locust trees being somewhat sickly. Fig and pear trees scattered about were neglected and unkept. An area in front of the residence had been staked, apparently for grapes.

On the tract of witness No. 21 cypress, pepper, and eucalyptus trees about the house were found to be in normal condition. Wheat was nearly a foot high with some oat plants intermixed, and a rather large number of mustard plants. No discoloration was noted.

On the places of witnesses Nos. 24 and 28 there seemed to be only volunteer crops. On the former the wild oats were spotted with Helminthosporium. Mustard was very abundant. The gulches across the creek supported a luxuriant growth of thistles.

On the place of witness No. 27 grain was very thrifty in appearance close to the fence and a little shorter in the open field. At a point near the property of witness No. 37 the wild oats showed a distinct terminal bleaching of the blades, but not closely resembling smoke injury. The bleaching had occurred some time earlier, and its exact cause could not be determined. Wheat was nearly a foot high in the main field and about 2 feet high along the border. An old vineyard was noted beyond the pumping station.

On the property of witness No. 37 a large assortment of ornamental plants about the residence was in good condition. East of the road an area of alfalfa and grain was observed, the former showing some mildew.

On the remaining places along the road no special notes were made except that volunteer grain was observed from time to time, as were also native species and shade trees, and found to be free from evidences of smoke injury. On the place of witness No. 38 alfalfa plants were closely examined and found to be in normal condition.

March 28, 1914.—Pear trees on the place of witness No. 17 were in bloom. The oats were about a foot in height and free from discoloration. Fig trees were beginning to open their leaves.

Opposite this place on the property of witness No. 35 a rather large number of native species, including filaree, burr clover, mustard, chickweed, and dock were examined. The dock was somewhat infected with a fungus, probably Ovularia, which produces round spots. Thrips markings were numerous on the barley plants. The lower blades showed whitish margins and considerable yellowish tissue.

Opposite the residence of witness No. 16 the oats had developed two and three culms per plant. Native species as well as cultivated species were free from signs of smoke injury.

On the place of witness No. 18 the quince trees were in flower and showed some discoloration due to the normal death of the oldest leaves. Roses, apples, figs, cherries, apricots, and peaches were in normal condition, save that the cherries were not thrifty. The almond trees

appeared to be in full leaf and nuts were quite well developed. Barley on plowed land opposite the residence of witness No. 19 was in good condition. It had reached a height of about 6 inches. There was a small amount of yellowish discoloration present, and whitish margins were noted on certain blades. Filaree, mustard, burr clover, and an aquatic butter cup (*Ranunculus muricatus*) were noted and found to be free from discoloration.

Several pear trees on the place of witness No. 19 had gone out of bloom and others were in full bloom. Many dead twigs were noted on the oak trees. Mustard, chickweed, burr clover, and volunteer grain were examined and found to be normal.

On the place of witness No. 16 shoots were developing in the vineyard and were several inches in length. Most of the orchard varieties were in leaf. The oats north of the residence were about a foot in height and quite uniform. Mustard was abundant in spots. No discoloration of either was noted.

Barley on the place of witness No. 29 was about a foot in height. The old orchard trees had not been pruned nor cultivated.

The grain on the place of witness No. 21 was 12 to 14 inches in height, and no discoloration of either the wild oats or the wheat was noted.

On the place of witness No. 27 the grain along the border—mostly wild oats—was about 3 feet high. Mustard among these plants was 5 to 6 feet high. The wheat was about a foot in height in the open field. Leaves were developing on the vines in spots. Other areas were still dormant. The discoloration noted on the former date was still present, but was not progressing; that is, only those blades formerly noted in this condition were affected.

At other points along the road between this point and Vallejo, examinations were made of the native species and cultivated crops, and no conditions were found that suggested smoke injury.

From the reports on the various farms in the Vallejo-Benicia region, over which the emanations from the Selby smelter pass, it will be seen that during the period from March 12 to May 8 damage to vegetation was limited to a small area or strip along the water front extending from Vallejo to Glen Cove, approximately, and a small additional area on the water front in Benicia. The number of species affected was small—barley, wild oats, broncho or brome grass, a few other varieties of grass, burr clover, mustard, filaree, Anagallis, mallow, Eriogonum, chickweed, and lupine. The barley, broncho grass, filaree, and mallow were the only species affected beyond a small area about the so-called Dos Reis Cove. At this point there were few fumigations of sufficient strength to injure vegetation—really only one strong enough to approach economic damage even to barley, one of the most sensitive crops.

Examination of specimens taken on the various farms suggests the desirablility of qualifying the above statement. A few barley blades, taken on the place of witness No. 32, were marked by small white spots slightly stained in a manner closely resembling, if not identical with, markings produced by sulphur dioxide in the experimental fumigation work. When these samples were taken the idea of smelter smoke as a casual agent was abandoned for the reasons that there were so few to be found, and the place of witness No. 32 did not seem exposed to smoke injury, and further that these markings were not those commonly found about smelters. Such markings were most numerous in the test plats given weak fumigations. It is to be noted that the place of witness No. 32 is in line with the place of witness No. 132 (where there were distinct smoke markings) and the smelter.

I am strongly of the opinion that the foliar markings of the barley and other plants affected by the gas from the smelter were insufficient to cause material reduction in the yield of crops in question.

Had my investigation begun a little earlier in the season it would have covered the part of the year in which damage to grain crops is possible. The period covered was sufficient to warrant the statement that there was no damage to spring and winter sown grain beyond the conditions above noted, as it was possible in the case of all grain or grain hay fields, save volunteer crops, to determine the fact of earlier injury or the absence of it by an examination of the oldest grain blades.

Orchard varieties and most of the truck crops, being less sensitive to smoke injury than grain (barley and oats), it does not seem probable that there was any damage inflicted through that channel. All orchards and gardens were a mile or more from the point of greatest damage. The residence lot and orchard on the place of witness No. 25 was almost directly in the line of the strongest fumigation (or perhaps it would be more nearly correct to say the most effective fumigation), and in this case there was a wide expanse of rolling territory between the point of most noticeable effect and the garden. Beyond one barley blade, which showed the characteristic discoloration of smoke injury, there was apparently no effect on the place of witness No. 25 throughout the period. As it is possible to find isolated specimens of almost every species beyond the possible limit of smoke injury which are marked by some other agent in a manner almost, if not quite, indistinguishable from the effects of smelter smoke, it does not seem justifiable to attribute a discoloration of one leaf or one blade of any species to smelter smoke when there is no other evidence.

The greater part of the area in which smoke markings were observable during the period of this investigation was not under cultivation

but was devoted to pasturage. Most of the vegetation over this area consisted of early maturing species such as filaree, burr clover, and certain annual grasses. Thus the hills early assumed a brownish or discolored appearance. This was pointed out on one or more occasions as evidence of smoke damage.

During the investigation particular care was taken to avoid conversation with farmers living in the community and all others who might be complainants, but several persons did break through the line of defense on various occasions. Witness No. 45, residing well out toward the western limits of Benicia, and one of his neighbors gave information relative to the "unbearableness" of the "gas" and "acids" from the smelter on the water and in the vicinity of their homes. Witness made loud complaint of damage to fruit trees and garden truck on his own place. An examination revealed no trace of smoke injury, though some of the most sensitive kinds of vegetation were present.

Witness's neighbor, witness No. 76, complained of damage to potatoes, alleging that they did not grow any more when the wind turned to the west, which happened late in April or early in May. Such beliefs are doubtless founded upon the fact that potatoes begin to show the presence of diseases (early blight, wilt, and rosette) about the time indicated. The potato is not at all sensitive to smelter smoke.

Witness No. 11 was of the opinion that the soil had been poisoned, which ought to account for his shortage in wheat, and asserted that the greatest damage from smelter fumes occurred in the fall when vegetation was dry, a hypothesis considerably at variance with facts. The fall damage referred to pertained mostly to stock, as it was thought that there was by that time an accumulation of poisonous material in or on the blades of grass.

Witness No. 4, without knowing what I was investigating, betrayed his feelings on the subject by stating that there was no use to attempt growing fruit or anything else, as nothing would grow while the smelter was in operation.

A woman living on the roadside at the west limits of Benicia stated that smoke was unendurable at certain times where she lived and that nothing grew in her garden as it ought on that account. No conditions whatever could be found in her garden, which contained a large assortment of plants, many of which were quite sensitive to sulphur dioxide, which would indicate smelter-smoke damage.

It was said that many people in the region complained of the odor of smelter smoke to the effect that it was sickening and nauseating. I was able to detect the odor of sulphur dioxide on one or two occasions while investigating in the region. The odor was quite faint, and was encountered at a point on the property of witnesses Nos. 1

and 1A some distance from any residence. The odor that pervades the atmosphere about the town of Oleum was encountered several times in the Vallejo-Benicia region. I have, myself, attributed the odor of bogs and various other odors to the emanations from a smelter in smelting communities, until I found that the direction of the wind was such that smelter emanations could not have been carried to the point at which the odor was noted. I have found many persons in smelting communities making such mistakes.

As irrigation water is not available, orcharding can not be practiced in the district except the raising of fruit for home consumption, and that only where water can be pumped or supplied in small quantities from spring runs. The family orchard on the place of witness No. 12 was well tilled and presented a fine appearance up to the end of this period of investigation, but favorable location with respect to soil and moisture conditions were probably the explanation. Of the two remaining family orchards under cultivation one looked fairly well but was not producing well. On nearly every place visited I noted several fruit trees of various sorts, neglected and generally in miserable condition. I found no evidence of smelter-smoke damage to fruit trees at any point visited.

Grain raising and pasturage seemed to be the only pursuits with any promise of profit that could be indulged in. Though the region is very rolling, most of the land seems to have been plowed and sowed to grain at some time. Grain can not be grown continuously on the same land and close pasturing will prove disastrous after a time to many of the common forage plants. Only those that fruit close to the ground are likely to survive many years. In general, then, I consider the region relatively low in agricultural value. To make a living in such a region farmers must be alert and active, putting forth every effort. Half-hearted farming in most instances accounts for the shortages complained of by residents of the smoke zone.

In reference to fungous diseases, two species of Helminthosporium were found on barley. One of these, *H. graminum*, was common on the place of witness No. 95. Its effects are noticeable quite early in the season. Infected plants show a sickly, dwarfed condition, accompanied by light streaks in the blades (called blade stripe), extending even to the bases of the sheaths. The discolored tissue becomes dark after a time. The kernels fail to mature, resulting in a condition referred to as dead head. Affected plants often yield nothing. The second species (unidentified) causes dark spots on the blades, frequently the premature death of entire blades.

A species of the same genus was common on oat blades, causing purple or brownish spots. This species was relatively unimportant though common.

DOCK DISEASE AND SPRAY INJURY.
1, Diseased Dock Leaf from Davis; 2, Diseased Dock Leaf from Vallejo;
3, Spray Injury to Leaf of Cherry Tree; 4, Spray Injury to Leaf of Apple Tree.

FUNGOUS INJURY TO BARLEY.
1, Blades from Place of Witness No. 25; 2, Blades from University Farm at Davis; 3, Blades from Place of Witness No. 12.

SMOKE INJURY TO GRAIN.
1, Wild oats from Place of Witnesses Nos. 1 and 2; 2, Barley from Place of Witness No. 132.

INJURY TO LEAVES BY ROOT DISEASE, LEAF MINER, AND CALICO BUG.
1, Injury by Root Disease, Leaves of Almond Tree; 2, Injury by Calico Bug, Leaves of Black Mustard; 3, Injury by Leaf Miner, Leaves of Wind-Mill Pink; 4, Injury by Leaf Miner, Leaves of Lupine.

CHLOROTIC CONDITION OF BARLEY FROM VALLEJO FIELD, OUTSIDE OF EXPERIMENTAL PLOTS

In certain fields mildew was abundant, causing premature death to oat blades.

A species of rye grass was found badly infected with a smut, causing splitting of the blades and sheaths. This species of grass was not important as stock feed on account of its tough inedible character.

Several other varieties of grass were infected with leaf-spot fungi which caused considerable discoloration of the blades and premature death of many.

Considerable work has lately been done upon the subject of wheat infections by soil fungi. The idea is becoming common, among plant pathologists, that the continued growing of one crop on the same soil results in decline in yield not so much on account of exhaustion of the soil as on account of the multiplication of soil organisms that attack the roots and even the above-ground parts of the crop. In one experiment that I conducted, elsewhere, wheat plats sprinkled with soil from old wheat land yielded considerably less than similar plats without the sprinkling of old wheat land soil.

As to insect pests a tortricid leaf roller was found defoliating pear trees in one orchard and doing considerable damage to pears and plums in other orchards.

The greatest infestation of woolly aphis I have ever seen was noted on apple trees in the orchard of witness No. 5, where it was evident that trees were being killed by that pest.

The prune aphis was abundant on some places.

Several species of scale insects were noted in most of the orchards examined. In some instances the infestation was light, though in others it was rather serious.

On several native species of vegetation I found leaf-miner injury (See Pl. XXXVI) and markings produced by moth larvæ that might readily be taken for smoke injury. This does not signify any close resemblance to smoke injury, as unscientific persons point out every sort of scratch or blemish of plant leaves as evidence of smoke injury.

One of the most important cases of insect injury was that of the Hessian fly on the place of witness No. 23, elsewhere discussed.

Other insect pests and fungous disease were found in the region, but reference to each specifically is not thought necessary.

INSECT PESTS IN THE SELBY SMOKE ZONE.

By R. W. Doane.

INTRODUCTION.

Following the instructions of the commission I made several trips to the Selby smoke zone during October and November, 1913, to study the condition of the orchards and other vegetation there and to note particularly to what extent the existing injury was due to insects.

In January, 1914, I began a short series of experiments or demonstrations to show that with proper cultivation, pruning, and spraying many of the orchards which are now almost worthless could be brought into bearing again and produce a normal amount of good, clean fruit. On account of pressure of other work these demonstrations were not pushed to their logical end, but enough was done to show conclusively that a large part of the trouble that is ordinarily charged to smelter-smoke injury is due to lack of care in the orchard or field.

Most of the orchards in this region are small home orchards, containing a few trees of various kinds, intended to furnish fruit for home use. There are few large orchards where fruit raising is conducted on a commercial basis, and I visited no orchards that showed that they had been cared for as an orchard must be cared for if it is going to yield the returns that it should. In the very best fruit-growing sections, under the most favorable conditions, it is necessary to pay careful attention to the condition of the soil and to pruning and spraying if profitable returns are to be expected. Many of the orchards, particularly the small ones, in the region studied remain unplowed from year to year. Often they are used for pasture. Very few show evidence of careful, intelligent pruning, and I believe that very few, if any, of them have ever been sprayed.

Neglected, unplowed orchards are hardly worthy of consideration, because such places have little fruit and contain many dead and dying trees in whatever region they may be found. Usually the insect pests and plant diseases play a prominent part in bringing about the early destruction of the trees in these orchards.

I will not now attempt to give a complete list of the injurious insects in the orchards of the smoke zone, but will call attention to a few that are of particular interest, because the damage they do is often mistaken for injury due to smelter smoke.

Several species of scale insects are common in nearly all of the orchards. The black scale, *Saisseta oleae* Bern., is in practically all orchards. Like other scale insects of this group, the black scale secretes an abundance of honeydew, minute drops of which fall on the leaves and branches, often covering them with a sweet sticky coating in which a black sooty mold grows, giving the trees a noticeable black appearance. This black smut on the trees is the thing that is most commonly complained of, as practically all of the people in the smoke zone believe it to be due to smelter smoke. It not only covers the leaves and branches of the tree, but is often all over the trunk of the tree and sometimes covers the fruit to such an extent as to make it most unattractive. I may say in passing that not only the fruit growers of the smoke zone, but many others who have had their attention called to the conditions there, believe the black smut is due to smelter smoke, and if this factor could be removed from the case most of the orchardists would find much less cause for believing that their trees were being injured by the smelter. I believe, too, that when they know the true source of the trouble many of them will take steps to control the scale insects.

The brown apricot scale, *Lecanium corni* Bouche, is also found in many of the orchards. In many places this is often regarded as one of the serious pests of orchard and other trees, not only on account of the damage that the insects do by sucking the sap from the plant, but because they secrete so much honeydew that the fruit and leaves of the trees often become covered with the black, sooty mold.

The frosted scale, *Lecanium pruinosum* Coq., is also found throughout the smoke zone, but it is not as abundant as the black scale and the brown apricot scale. Its appearance and habits are somewhat like the last-named species.

Belonging to the same group of scale insects is the soft brown scale, *Coccus hesperidum* Linn, which is found very commonly on citrus trees. Practically all of the orange and lemon trees in the smoke zone were more or less seriously infested, and as this insect, too, secretes an abundance of honeydew, the leaves and fruit were usually covered with the black, sooty mold which grows in this secretion.

The cottony cushion scale, *Icerya purchasi* Mask., was found on many of the citrus trees. It, too, secretes an abundance of honeydew. Without an exception, the owners of the trees that were infested with these scale insects believed that the black, sooty mold on the leaves and fruit was due to smelter smoke, and it was often difficult to convince them that the trees could be kept clean if the insects were destroyed.

The San José scale, *Aspidiotus perniciosus* Comst., which has been long regarded as one of the most serious pests of fruit trees, was found in many orchards in the smoke zone. Some apple trees were found to

have the bark of the trunk and larger limbs quite covered with this insect, and the trees showed very clearly that they were suffering as a result of this heavy infestation. As the insects are so small and the scaly covering is just the color of the bark, the owners of the trees usually do not know that the pest is in their orchards until attention is called to it by some one who readily recognizes the insect and its work.

Within recent years the European pear scale, *Epidiaspis pyricola* Del Guercio, has come to be regarded by many as a pest almost as important as the San José scale in some parts of California at least. The scale of the female is very similar to that of the San José scale, and may readily be mistaken for it unless examined carefully. The scale of the male is, however, quite distinct, being elongate and white.

The European pear scales are often found under the moss on the trees. For this reason they may be easily overlooked, even if one is examining the trees for them. The moss protects them from their natural enemies and makes it more difficult to kill the insects with any spray material. Best results are obtained by using a spray that will clean the moss from the tree as well as kill the insects.

This pest is common in the Selby smoke zone and many trees are being killed by it, the owners, of course, charging the trouble to smelter smoke.

The greedy scale, *Aspidiotus rapax* Comst., is also common throughout the smoke zone, but it is not usually regarded as a serious pest.

The oleander scale, *Aspidiotus hederae* Vall., like the greedy scale, is a common insect on a great variety of plants in many places, and is not usually regarded as a serious pest. Sometimes, however, it occurs in great numbers, or attacks plants that are particularly susceptible to injury by it, and considerable loss may result. In a large field of currant bushes I noticed that many of the bushes were dying in spots throughout the field. I was unable to account for this condition until I dug down and found the crown and the roots badly infested with this scale insect. An examination of other dead or dying bushes and a comparison with bushes on which few or no scale insects occurred, showed that this pest was responsible for the death of many bushes throughout the field.

The oyster-shell scale, *Lepidosaphes ulmi* Linn., is a larger, much more conspicuous, insect than any of the members of the genus *Aspidiotus*. It occurs in incredible numbers throughout the smoke zone, often literally covering the whole tree. Light infestations of this insect are not usually regarded as serious, but when it becomes as abundant as it often is here, the trees can not but suffer.

The cypress Sphaerococcus, *Sphaerococcus cuppressi* Ehrh., is an important enemy of the Monterey cypress in the smoke zone. Many of the trees that have died or are dying are badly infested with this

pest, and it is doubtless one of the important factors that has brought about the present deplorable condition of so many of the trees. It is more fully discussed on a later page.

The woolly aphis, *Schizoneura lanigera* Hausm., is common in all of the orchards of the smoke zone. In some of the younger orchards it is seriously injuring the trees. It occurs on both the roots and the branches, being easily detected on account of the white woolly secretion that covers the insects as they group themselves on the underside of young twigs or shoots or on the new growth around any kind of a wound. They often cause considerable knots or swellings on the affected parts of the trees. The roots particularly are apt to become badly affected and misshapen on account of the many galls that characterize the work of this pest.

In this way many of the smaller roots are entirely destroyed and young trees are thus seriously injured, and if not killed outright, they become so stunted that they never make the trees they should have made. It is a difficult insect to control, as it is hard to get anything that will penetrate the soil and kill the insects without injuring the tree. Nurserymen should not be allowed to sell growers infested nursery stock.

The rosy apple aphis, *Aphis sorbi* Kalt., is another serious pest of the apple trees in the smoke zone, doing particular damage to young apple trees by curling and destroying the leaves and thus keeping them from performing their normal function. As this aphis works only above the ground, its work is much more evident to the grower and can hardly be mistaken for anything else. But it secretes a great deal of honeydew, in which the black, sooty mold grows, and this is usually charged to smelter smoke.

The mealy plum louse, *Hyalopterus arundinis* Fab., is the most abundant aphis in the smoke region attacking plums. The first broods hatch from eggs that have passed the winter on the twigs. The young aphids settle on the under sides of the young leaves and begin feeding. They soon begin to give birth to living young, which, in turn, produce other generations. Early in the summer the number of these pests have increased to such an extent that they cover the under sides of most of the leaves on many trees. Such infested leaves usually do not curl, but they soon turn yellow and fall early. Before midsummer, most of the aphids have left the prune trees, having acquired wings and migrated to grasses where they feed until fall. A few migrants return to the trees in the fall and a generation is produced that lays the winter eggs.

As these aphids are just the color of the leaves, they may often remain unnoticed, even when they occur in great enough numbers to cover the under sides of the leaves. The great amount of honeydew that they secrete soon attracts attention because the leaves

become sticky and the black, sooty mold soon begins to grow in it. In many orchards the trees become very black on account of the great amount of this honeydew. Unfortunately, the sooty mold remains on the tree long after the aphids have left it, and the grower, at a loss to explain the presence of the black substance on his trees in any other way, charges it up to smelter smoke. Again and again I explained the relation of the scale insects and the aphids to the orchardists in the smoke region, but to most of them the smelter smoke was an easier explanation, and so was the one usually accepted.

There are still other insects that by secreting honeydew cause the leaves of the plant on which they are feeding to become blackened by the growth of black fungi, but attention will be called to only one more. The grape-leaf hopper, *Typhlocyba comes* Say., feeds on the grapevine leaves, often conspicuously spotting and blackening them. As the insect sucks the sap from the leaf, small white spots are made where the beak has been inserted. Sometimes these spots are so numerous that they coalesce and form dry, brown patches. Badly infested leaves usually dry and fall early. As the insects are feeding they secrete more or less honeydew, but more disgusting still are the small, black spots of excreta that often cover the leaves and berries, making the latter unfit for food unless they are washed.

The work of the apple-leaf hoppers, *Empoasca mali* LeB., on the apple leaves is much like that of the grapevine leaf hopper on the foliage of the grape. Although this insect is common throughout the smoke region, it is not of much economic importance, and is listed only because the effect of its work on the leaves may be mistaken for smelter-smoke injury.

Other species of leaf hoppers occur on many other plants, melon vines, cucumber vines, and other garden plants, often suffering considerably from the attacks of these insects, which suck the sap from the leaves and cause them to dry and turn brown prematurely.

The pear thrips, *Euthrips pyri* Daniel, was found commonly throughout the orchards in the smoke zone, but we did not see them abundant enough in any of the orchards to be of much economic importance this year. The history of this pest in Santa Clara Valley shows us that it may become of prime importance where climatic and other conditions are favorable.

The bean thrips, *Heliothrips fasciatus* Pergande, was much more abundant and in many gardens was doing a great deal of damage to almost all kinds of garden truck. As it usually works on the under sides of the leaves, it does not usually attract attention, and the dried, yellowish or brownish condition of the leaves is apt to be ascribed to other causes.

The spotted flower beetle, *Diabrotica soror* Lec., is also a common garden pest, as it feeds on the foliage of almost all kinds of cultivated

plants, sometimes almost, or quite, defoliating them, and often ruining the blossoms. The beetle is easily seen and its work is distinct, so it need not be confused with anything else.

A small, red mite, *Bryobia pratensis* Garman, commonly known as the "red spider," is destructively abundant in many orchards, doing particular damage to almond trees. The eggs of this mite are to be found during the winter on the under sides of branches of the tree. As soon as the first leaves begin to unfold the mites are ready to begin feeding on them and often a very small leaf will be attacked by more than a score of these little pests. As the leaves grow larger, they become more seriously affected, and long before they have attained their normal size and development, they begin to turn grayish, then brownish, and, in bad seasons, many almond trees are often defoliated before midsummer.

As the mites are so small that they can hardly be seen except with the aid of a lens, their presence on the trees is usually not noticed by the orchardist, and the discolored leaves and early falling is thought to be due to smelter smoke.

Another mite, the two-spotted mite, *Tetranychus bimaculatus* Harv., is sometimes also called "red spider." This occurs on plums, prunes, berries, and many other trees and plants, sometimes almost or quite defoliating them early in the season. While present in many orchards and gardens in the Selby smoke zone, it does not seem to be as important as *Bryobia*.

The pear-leaf blister mite, *Eriophes pyri* Pgst., enters the pear leaves while they are very small, sometimes while they are yet in the bud. As it feeds within the tissues of the leaf, it causes conspicuous red spots, which later may become greenish, then brown. Although many orchardists are familiar with the work of this insect and its effect on the leaf, not a few in the smoke zone believe that the spots on the leaves are caused by smelter smoke.

The work of the pear slug, *Caliroa cerasi* Linn, is distinctive and need not be, but frequently is, mistaken for other injury. These slug-like larvae feed on the upper surface of the leaf, eating away all the green part and causing the lower part to dry and turn brown. The adults are small black sawflies.

The peach-twig borer, *Anarsia lineatella* Zell., bores its way into the tender young shoots on the peach trees, often killing in this way a large part of the new growth, particularly on young trees, where the evidences of its work are most prominent. The dead twigs at once attract attention, and as there is no external evidence of insect or other injury some orchardists believe this condition to be due to smelter-smoke injury. Most of the growers, however, recognize the work of this insect.

A small black weevil, which seems only recently to have developed into a pest of any importance, was found feeding on the young leaves of peach, plum, cherry, and apple trees, being particularly abundant during April. When the infestation is bad, nearly all of the foliage may be destroyed. In one orchard this weevil and the leaf rollers quite defoliated a young apple tree. New leaves will soon be formed, but the retarding of the development of the tree, caused by the loss of so many of the first leaves, may be of much importance.

The codling moth, *Cydia pomonella* Linn., is common in all orchards. No efforts are made to control it in the Selby smoke zone. Everyone is familiar with the worm in the apples and pears, but few realize that these larvae are responsible for so much of the fruit dropping early in the season. Many times our attention was called to the fact that the apples and pears dropped from the trees early in the season, before they were mature. The orchardists believed that this was because the smelter smoke had injured the trees or the fruit. We were not in the orchards when the fruit was falling, but as nearly all of the fruit that remained on the trees was infested with the coddling-moth larvae, it is safe to say that a large percentage of the fruit that fell was also infested.

Throughout the region covered by the investigation many of the grapevines were found to be dying. Neglect was possibly responsible for the death of some of these vines, but the grapevine phylloxera, *Phylloxera vastatrix* Planchon, probably killed many more. This insect works in a vineyard in such a way that unless one is familiar with the effects on the vines its presence may never be suspected. The phylloxera, which are very small bronze-colored aphis, attack the healthy roots, usually causing a swelling at the point where they puncture the tissue. When the infestation is severe these gall-like growths may be so common as to almost or quite touch each other, and as the cells in the affected parts soon break up and decay, the whole root system may be seriously affected. In this way the young, vigorous roots may early be destroyed, and the vine killed outright, or, if the infestation is a little less severe, the vine may become weakened but live for a long while in an unthrifty condition, bearing little or no fruit. The phylloxera do not seem to thrive on such weakened vines, and an examination may fail to reveal any on the roots, but an examination of comparatively healthy vines near by will usually reveal the insects.

I do not know that this insect has been reported from this region before. None of the growers suspected its presence in their vineyards, and many, being at a loss to account for the condition of their vines, held the smelter smoke to be responsible for the injury.

Some of the grapevine roots examined looked as if they had been injured by the grape-root worm, *Adoxus obscurus* Linn., but none of

the insects was found, and I am not sure that it occurs in the smoke zone.

In the Carquinez cemetery and other places many of the Monterey cypress trees are dying. I have already called attention to the scale insects that are attacking these trees and doubtless doing more or less injury, but not being entirely responsible for the death of the trees. As soon as one of these trees is weakened from any cause it may be attacked by hordes of small beetles, *Phloeosinus cupressi* Hopk., which bore into the cambium and make longitudinal chambers in which they lay their eggs. The larvae that hatch from these eggs bore out at right angles from the brood chamber, and if many of them are in the tree they soon girdle it. Many trees that might have survived temporary unfavorable conditions are thus entirely destroyed, for as soon as these beetles begin working in the cambium the tree is doomed.

The same insects sometimes attack the twigs and smaller limbs of Monterey cypress that are apparently in full vigor, and in this way may do considerable damage. In some places in the smoke zone I found trees which showed this work conspicuously.

This same insect is known throughout some parts of California as the most important pest of the Lawson cypress, for it affects not only the twigs, but bores into the cambium of the trees when they are seemingly perfectly sound. The burrows made by the beetles and the larvae kill the trees in a short time. Some investigators believe that the beetle may in the same way attack sound Monterey cypress and kill them, but others think that these trees must first be weakened by drought or some other agent.

Many of the Monterey cypress trees in the vicinity of Palo Alto and Stanford University are now dying in the same way as were the trees in the Carquinez cemetery and around Benicia. With the aid of an advanced student I am now making a study of these trees. Sometimes a score or more of these trees will be found to be dying in small groves or rows. As soon as the trees begin to show signs of dying, we find the beetles at work in them, but we are not yet convinced that the beetles are the primary cause of the trouble. As some of these dying trees are to be found on the hillsides and others in the valleys, the location or soil does not seem to be an important factor.

My whole time during the days that I was engaged in this work was given to the study of the trees, vines, and garden plants. No study was made of the insects that were infesting the wheat or other grains. Since finishing this work one of the plant pathologists, Mr. W. W. Jones, submitted to me specimens of wheat straws he had collected on one of the farms near Benicia. An examination of

these showed that they were very badly infested with Hessian fly, the insect being found at that time in the pupal or "flaxseed" stage. Mr. Jones will doubtless report on the condition of the field at the time he collected these specimens, and I will add a few words in regard to the way this insect works and affects the plants.

The flies lay their eggs on the leaves, and the young larvæ which hatch from them make their way toward the base of the stem, where, protected by the leaf sheath, they begin sucking the juice from the plant. The young wheat when attacked in the fall usually turns yellow, and if the attack is serious, stops growing. The pest usually appears first in the less thrifty parts of the field, but if the infestation is bad, it may show up over the whole field. Often the main plant is destroyed and tillers or side shoots are formed; thus there will often be formed many small stems instead of fewer strong, thrifty stems. When the larva becomes full grown it changes to a pupal stage. The pupa case is small, brown, flattened, oval, and looks so much like a flaxseed that this stage is commonly known as the "flaxseed" stage. It was this stage that I found in the wheat stems that Mr. Jones submitted to me. The insect passes the winter in this stage and the flies that issue early in the spring lay their eggs on the young spring wheat, and much damage may result from the attacks of this spring brood. There may be two or three, or even four generations during the year in some localities.

This insect has never been a very serious pest in California, and its life history has not been carefully worked out here. Under certain conditions, however, it sometimes becomes of considerable economic importance, particularly in the San Francisco Bay region. It seems that the interior valleys are too dry for its development.

THE DEMONSTRATION EXPERIMENT.

Realizing that the poor condition of many of the orchards in the region where these investigations were being made was due to lack of cultivation, pruning, and spraying, I planned a short series of experiments to try to demonstrate what might be done in some of these orchards if they were given proper care. Unfavorable weather conditions and the difficulty I had in getting the work done interfered greatly with my plans, but enough was accomplished to show that the trees, if not already too far gone from neglect, will quickly respond to proper treatment.

These experiments were conducted on three different places. One of the orchards selected was on the place of witness No. 24, just east of Benicia. This orchard is situated on the hillside west of the house and contains 50 or 60 trees, including a few apricot, plum, cherry, pear, and apple trees. On the place of witness No. 26, just north, a few trees that were badly infested with the European pear scale,

Epidiaspis pyricola Del Guercio, were selected for treatment. The other trees used in the experiments were on the place of witness No. 5 in Glen Cove. We had planned to do the first work in December, but the rainy weather made this impracticable.

On January 9 I went into the orchard of witness No. 24, ready to spray, but found that the trees had not yet been pruned. This made it impossible to give them as thorough a treatment as I would have liked to have given them, but as the season was getting late, I sprayed a few of the trees as follows:

Five peach trees, one small apple tree, one pear tree, one damson plum tree, one apricot tree, using "Rex sulphur-lime" spray at the rate of 1 part to 10 parts of water. The apple tree was badly affected with oyster-shell scale, *Lepidosaphes ulmi* Linn. As the overwintering eggs of this insect are safely protected underneath the body of the old scale, I hardly expected to kill them by this treatment, but thought the experiment might be worth while. The rest of the trees were all badly affected with black scale, *Lecanium oleae* Bern., and some of them had a few greedy scales, *Aspidiotus rapax* Comst. Most of these trees were very black because of the presence of the black sooty mold that grows in the honeydew that is secreted by black scale and by aphis.

On February 14, I found that all of the trees in this orchard had been severely pruned. So many of the small limbs had been removed that the trunks of the trees were badly exposed, and they may suffer from the direct rays of the sun during the warm spring and early summer. But this pruning made the trees easier to spray, and as I was not thoroughly satisfied with my first spraying, I gave all the trees a second treatment, using the same materials at the same strength. The buds were just beginning to swell on all of these trees, but they were not opened far enough to make it dangerous to use the spray at this strength.

On the same day I selected three other peach trees and sprayed them with distillate emulsion, using 1 gallon of the emulsion to 16 gallons of water. These trees were badly infested with black scale. The orchard had not yet been plowed.

January 10 I found that witness No. 5 had pruned a few almond and prune trees. On this day I sprayed four almond trees, four prune trees, and four small apricot trees, the apricot trees and two of the prune trees had not been pruned. I used the sulphur-lime spray, 1 part to 10 of water. The day was cold and there was a little wind and fog, but we succeeded in getting the trees covered fairly well.

January 31 I sprayed again in the orchard of witness No. 5, using "Rex distillate emulsion," 1 part to 16 parts of water. In this experiment I used three unpruned prune trees just above the ones that had been sprayed with "sulphur lime." The almond trees were

badly infested with black scale and the lower sides of most of the limbs were literally covered with the eggs of the red spider or mite, *Bryobia pratensis* Garman. The prune trees were badly infested with black scale, while the apricot trees had only a few black scales.

February 14 I sprayed two small plum trees and two small pear trees in the orchard of witness No. 26. These trees were badly infested with European pear scale, *Epidiaspis pyricola* Del Guercio. In this experiment we used a distillate emulsion, 1 to 16.

March 7 I inspected the sprayed trees in the orchards of witnesses Nos. 5 and 26 to determine whether the spraying had had any effect on the time of blossoming. I could notice no perceptible difference in the amount of blossoms on the sprayed and the unsprayed trees. The peach trees were all just beginning to bloom at this time. The apricot trees showed only a few blossoms. The plum tree was just beginning to bloom. All of the almond trees in the orchard of witness No. 5 had dropped most of their blossoms and there appeared to be a fairly good set of nuts on all of the trees. At this time I noted no difference in the amount of almonds on the sprayed and unsprayed trees. The red spiders, or mites, had already begun to hatch on both the sprayed and unsprayed trees, although they were less abundant on the former. On the unsprayed trees many of the small leaves were already showing the effects of the spiders' work. One leaf, less than an inch long, had 53 of the mites feeding on it. Such leaves as this were already badly injured by the mites. While many of the eggs on the sprayed trees were hatching, the young mites seemed to be killed very soon after they issued, so that the leaves were not at all affected by them.

Most of the scale insects on the sprayed trees seemed to have been killed. The almond trees and the prune trees that had been sprayed with sulphur lime were looking much cleaner and brighter than the unsprayed trees. The prune trees that had been sprayed with distillate were still rather black and did not look any better than the unsprayed trees. I had expected that the distillate would clean the sooty mold off of the trees, but it did not seem to do it. A crude-oil emulsion would probably have served this purpose much better.

March 9 I examined the trees in the orchard of witness No. 26 that had been sprayed with the distillate, and found that nearly all of the scale had been killed, but a few live insects were to be found under the old bark in places where the spray had not penetrated.

April 11 I again inspected the orchard of witness of No. 24; it had recently been plowed. The ground evidently was not in good condition when it was plowed, for it was left in big chunks that would dry out rapidly and be hard to put into good condition unless more rains should soften the clods so that they could be harrowed to pieces. The black scale, *Saisseta oleal* Bern., on the unsprayed peach trees were

from one-quarter to one-half grown, and appeared in considerable numbers. There were also some frosty scales, *Lecanium pruinosum* Coq., that were about one-half grown, and were secreting considerable honeydew, which was dropping on the leaves directly below them. Few scales were to be found on the trees that were sprayed, and nearly all of these were dead. The mealy plum aphis, *Hyalopterus arundinis* Fab., were abundant on the plum trees, the undersides of many of the leaves were entirely covered, and on some of the twigs nearly all of the leaves were infested. These aphis were present on both the sprayed and unsprayed trees.

On the same day I visited again the orchard of witness No. 5. A comparison of the sprayed and unsprayed almond trees showed a striking difference in the number of scale insects and red spiders. Some of the limbs on the unsprayed trees showed an abundance of scale insects one-quarter to one-half grown, but they did not seem to be secreting honeydew at that time. The red spiders, or mites, were also bad on some of these trees. The young mites occurred in great masses among the eggs on the undersides of the limbs. They were also scattering through the leaves, many of the leaves being already pale and spotted on account of their work. The leaves on the sprayed trees were bright and clean and unspotted, and looked particularly fine when compared with the leaves of the unsprayed trees. There seemed to be more almonds on the sprayed than on the unsprayed trees.

The unsprayed prune trees showed a great many black scales one-quarter to one-half grown, and a few frosty scales. The aphis were rather abundant on the lower sides of the leaves. Three of the sprayed prune trees showed few scale insects, the fourth showed a few more, but not nearly so many as were found on the unsprayed trees. The three prune trees that were sprayed with the distillate had practically no scale on them, but they had aphis. All of the prune trees have bloomed heavily, but the set of prunes is light.

April 25, in company with two members of the commission, Messrs. Franklin and Gould, and Mr. Wells, of the commission staff, I again visited the orchards where the spraying had been done. The difference in the sprayed and unsprayed trees was even more striking than before.

In the orchard of witness No. 5 the leaves on the sprayed almond were clean and bright, with a healthy growth of foliage and a good set of nuts, while the unsprayed trees showed conspicuously the markings and coloring due to the attacks of the red spider. The scale on the unsprayed trees was also conspicuous, as most of them were nearly full grown. We found no scale on the sprayed almond trees. Many of the prune trees in this orchard, including those that had been sprayed, were badly infested with aphids *Hyalopterus arundinis* Fab.; the honeydew

that they secrete was already conspicuous on the leaves. It was suggested that it might be worth while to spray some of these trees with some insecticide that would kill the aphids. But as the season was well advanced and as the aphids had already inflicted almost as much injury as they could before their summer migration or before their natural enemies began to control them, I did not think it would be worth the while to spray these trees for demonstration purposes only. The presence on the leaves of the honeydew would cause the black, sooty mold to cover them so that much of the value of this demonstration on the prune trees would be lost for the sprayed prune trees would be almost or quite as black as the unsprayed trees. If these trees had been sprayed for the aphis earlier, they would have been in good condition. As most of the apricot trees in this orchard were in good condition, the effect of the spraying on the four apricot trees was not apparent.

In the orchard of witness No. 24 the difference between the sprayed and the unsprayed trees was not as noticeable as in the orchard of witness No. 5. Examination showed that the nearly full-grown scales were fairly abundant on many of the unsprayed trees; none was found on the sprayed trees. A more careful detailed examination may have shown a few scales on these sprayed trees, but it was evident that they would not be abundant enough to be of importance. The plum tree that was sprayed, as well as others unsprayed in the same orchard, was badly infested with aphis, *Hyalopterus arundinis* Fab., so it was to be expected that all of the plum trees, both sprayed and unsprayed, would be black with the sooty fungus later in the season. In this orchard I called the particular attention of the commissioners to the condition of some of the small apple trees that had been seriously injured by the attacks of rosy aphis, apple leaf rollers, and small black weevils. The weevil feeds on the foliage of the peach, plum, cherry, apple, and other trees. Its work was very noticeable on the peach trees, but was probably of more importance on some of the small apple trees, as it had destroyed such a large proportion of the already scanty foliage. Working with them were leaf rollers. These larvæ spin silken threads which fasten the edges of the leaves together, making a safe retreat within which they can feed on the tissues of the leaves or from which they can make excursions to other leaves. Where several of these are present on the tree, as they were in some instances in this orchard, the foliage is seriously affected. Many of the leaves that still remained on the trees were badly affected by rosy aphis. These aphis suck the sap from the leaf and cause it to curl in a characteristic manner. Most of these small apple trees are badly infested with oyster-shell scale. At the time of this visit the insects were still in the egg stage, but they will soon hatch and begin their work on the bark of the tree. Many of these trees which were suffering the loss

of their foliage also had their trunks badly affected by sunburn or canker and by attacks of the flat-headed apple-tree borer. With all of these troubles we can not expect the trees to thrive; it is remarkable that they are alive at all. The attention of the commissioners was also called to the condition of the cherry trees, which were dying from some fungus or bacterial disease that is working in the tops and limbs, and to an old vineyard, many of the vines of which have been killed by phylloxera. We found phylloxera to be present on some of the vines. Doubtless the present unprofitable condition of these old vines is due to the fact that phylloxera still occur in sufficient numbers to keep them in an unproductive condition.

NOTES ON CONDITIONS IN DIFFERENT ORCHARDS.

Having discussed the general conditions of the orchards in the region of Vallejo and Benicia, it may be worth while to give in some detail the notes taken in several different orchards; such will not only show the basis for my conclusions, but will give the information as to the general conditions of each of the orchards discussed. Many orchards other than those mentioned below were visited and inspected, but detailed notes in regard to them need not be given.

PLACE OF WITNESSES NOS. 1 AND 1A.

The orchard on the place of witnesses Nos. 1 and 1A was inspected on November 8, 1914. Notes made thereon follow:

The orchard on this place is in a fair state of cultivation. The pears appear to have been severely pruned to cut out the dead wood due to blight or other causes.

A few greedy scales, *Aspidiotus rapax* Comst., and a few pear tree slugs, *Caliroa cerasi* Linn., were found. San Jose scale, *Aspidiotus perniciosus* Comst., was bad on some of the trees, and doubtless is doing considerable injury.

The old trees nearest the cypress trees were nearly all dead. The tenant says that there has been no fruit on these trees for the last two years because they have been too dry.

The flat-headed borers, *Chrysobothris femorata* Fab., have entered the spots on the trunk that have been killed by blister and by canker and have worked not only in the dead part but have extended their work into the live wood.

The old plum trees in the back of the orchard are pruned so high that I could not reach the branches from the ground. The trunks are badly sunburned; in fact, these trees are now merely snags with a few short twigs toward the top. The tenant says that he does not expect fruit from them because they are too old. He has already taken some of them out. He makes no mention of smelter-smoke injury.

Some of the plum trees are black with the sooty mold that grows in the honeydew from the black scale that is abundant on the trees.

Certain pear trees that stand nearest to these black plum trees are not infested with the black scale, and the trunks and leaves are bright and clean.

The apricot trees are in much the same condition as the plum trees; that is, they are simply old snags that were pruned so high that none of the branches or leaves can be reached from the ground. The trees are pruned high, in order that the orchard may be used for raising grain.

Some of the cypress trees around this orchard were dying and are badly infested with the cypress Sphaerococcus, *Sphaerococcus cupresti* Ehrh., but the work of this insect is probably only one of the factors contributing to the death of the trees.

In the vineyard across the drive (I am not sure that this belonged to the same owner) all of the vines near the eucalyptus trees were dead. On other vines the grapevine leaf hoppers, *Typhlocyba comes* Say., were abundant, and the leaves showed plainly the effects of their work.

PLACE OF WITNESS NO. 25.

Place visited October 31, 1914.

In the old orchard south of the road I find the pear trees dropping their leaves. This is the normal autumnal dropping.

San Jose scale, *Aspidiotus perniciosus* Comst., is abundant on the trunks and limbs of the trees. This insect must be doing considerable damage.

The greedy scale, *Aspidiotus rapax* Comst., is quite abundant also, and probably doing some injury.

The black scale, *Sassita oleae* and the oyster-shell scale, *Lepidosaphes ulmi* Linn., also occur on the trees, but they are not abundant enough to be doing any injury.

The work of the pear slug, *Colisoa cerasi* Linn., is evident on many of the leaves. This work causes a browning which might very readily be mistaken for smoke injury.

The pear-leaf blister mite, *Eriophyes pyri* Pgst., is rather common in many of the leaves, causing injury that is often mistaken for smoke injury.

The codling-moth, *Cydia pomonella* Linn., larvæ and old cocoons are rather abundant under the bark of the trees. While the injury caused by this insect can not, of course, be mistaken for smoke injury, the insects seriously damage the crop, and all of these things need to be taken into consideration when estimating the amount of loss due to various causes in the orchard.

The cultivation of the orchard is only superficial, and there has been no attempt to plow close to the trees. The owner says that this orchard is no longer of any value, and he does not give it much care. He thinks that the smoke does him most damage during the summer time.

On the other side of the road, near the house, we found the raspberry bushes with many old dead leaves on them; some of the old vines showed about one-half of the leaves dead. This condition seemed to be the result of the bushes drying out. The grapevine leaf hopper, *Typhlocyba comes* Say., and two other species of hoppers were rather common on the raspberry leaves, causing white spots.

On the grape vines the leaf hoppers were abundant, causing conspicuous characteristic spottings of the leaves. This spotting is often mistaken for smoke injury.

There is considerable dead wood in the small orange trees close to the house. A few soft brown scale, *Coccus hesperidum*, Linn., were found on these trees, but there are not enough of them to be of much importance. The condition of the trees is probably due to drying out.

Five or six young navel-orange trees are badly injured by the work of the spotted flower beetle, *Diabrotica soror* Lec. This insect chews the tissues of the leaves, leaving them ragged. The soft brown scale is abundant on these trees.

On two of the small lemon trees we found a few black scale and a few of the soft brown scales.

The work of the peach-twig borer, *Anarsia lineatella* Zell., is conspicuous on the peach trees. The tips of the twigs and many of the lateral shoots have been killed. This injury is commonly supposed to be due to smelter smoke. The larvæ are now hibernating in little cells in the crotches of the trees.

The injury due to the work of the two-spotted mite, *Tetranychus bimaculatus* Harv., is rather conspicuous on the plum tree near the house. The leaves are rather spotted

and whitened. Some aphis, species undetermined, is causing the leaves to curl. A slug, probably a pear-tree slug, has also been at work on the plum trees.

The two-spotted mite is abundant on the watermelon vines, causing the leaves to turn brown, an injury that is usually ascribed to smelter smoke. The small green leaf hopper is also abundant on these vines. The black-spotted flower beetle, *Diabrotica soror* Lec., is also rather common on these vines, and is doing its part to destroy the foliage.

On the muskmelon vines the red-banded thrips, *Heliothrips fasciata* Pergande, are doing a good deal of damage. The browning of the leaves due to their work is conspicuous. The leaf hoppers are also bad on these vines.

The squash vines are also badly infested with the same thrips and leaf hoppers. Special attention should be called to the work of these insects on such vines as these and on other garden truck. These insects are so small that they usually escape the notice of the gardener, and as their work causes the leaves to turn pale, and often to turn brown in spots, practically all of the gardeners in all smelter regions believe that the injury caused by these insects is due to smelter smoke.

PLACE OF WITNESS NO. 34.

Inspection made October 31, 1914.

The orchards on this place have evidently been abandoned and are now being used for pasture. Many dead trees were found throughout the orchard, and the other trees are badly sunburned, broken, and infested with various kinds of insects, but the whole orchard is in such a condition that it would not be worth while to try to make any estimate of the amount of injury there.

CARQUINEZ CEMETERY.

Inspection made October 31, 1913.

Many of the Monterey cypress trees in this cemetery were dying. On the trees near the road that have been pruned for a hedge, I found a scale insect, *Sphaerococcus cupressi* Ehrh., abundant. This scale works on the trunk and branches of the tree and hides itself in the cracks and crevices as much as possible. The white, flocculent secretion that covers the insect and fills the crevices in which it is hiding makes it rather conspicuous, particularly if pieces of the old, rough bark are torn away. This insect is doubtless doing a great deal of damage to these trees, and I was at first inclined to ascribe the condition of the trees to its attacks. Upon examining other trees, however, I found many dying that were not badly infested with this scale insect, and, as later notes will show, I found the same insect common on cypress trees in the Benicia cemetery, where few of the trees were dying.

In some of the dying cypress trees I found a few bark-boring beetles at work, but as these insects seldom attack the cypress trees until they are weakened from other causes, I do not hold them entirely responsible for the condition of the trees.

My final conclusions in regard to these insects were that they are only one of the factors that are concerned in the killing of these trees.

GLEN COVE.

Inspection made October 31, 1913.

Some of the apple trees on this place are old and gnarled and badly affected by various insects. Some large wood borer has been working in the bark and wood of some of the trees, doing a great deal of damage. Nearly all of the trees are badly infested with oyster-shell scale, *Lepidosaphes ulmi* Linn.; many of the leaves are curled by aphis, *Aphis sorbi* Kalb.; red spiders, *Bryobia pratensis* Garman, are abundant on some, and much of the foliage is affected by apple mildew. A few leaf hoppers were also found on some of the trees.

On the almond trees I found many red spiders, *Bryobia pratensis* Garman. The old and young were still active, and there were many eggs on the lower sides of the branches. A few scale insects were also found on these trees.

PLACE OF WITNESS NO. 5.

Inspection made October 31, 1913.

The old almond trees have already lost most of their leaves. Those that remain are still infested with the mites, *Bryobia pratensis* Garman. On the under side of the twigs and smaller limbs I find an abundance of mite eggs.

The black scale, *Saisseta oleae* Bern., is also abundant on many of these trees. The trees themselves are black, being covered with a sooty mold which grows in the honeydew secreted by the infesting scale insects and aphis. This condition is, as I have pointed out in other parts of my report, commonly ascribed to smelter smoke. I have often called attention to the fact that only the trees that are affected with aphis or certain kinds of scale insects are blackened in this way. Other nearby trees, which are free from these insects, do not show this blackened condition.

In this same orchard the pear trees, fig trees, and others that are seldom seriously attacked by aphis or by *Lecaniums* are quite free from this black, sooty mold.

Many of the plum trees are black on account of the presence of this sooty mold. On such trees the black scale is abundant, and they were probably badly infested with aphis earlier in the season. The two-spotted mites, *Tetranychus bimaculatus* Harv., are abundant on these leaves. Not only do these mites do considerable damage to the leaves, but the fine webs that they spin for the protection of their eggs and young help to hold the sooty mold on the leaves, thus making them look worse.

Many of the almond trees on the hill are badly infested with black scale, and the black mold on the trees is growing in the secretion from these insects. The under sides of some of the limbs of these trees show large masses of eggs of the red spider, *Bryobia pratensis* Garman.

The apricot trees on the hill near the barn are in good condition. The leaves are beginning to fall. I found a few of the two-spotted mites on some of the leaves.

The grapevines have had practically all of the leaves stripped from them by the sheep that have been feeding in the vineyard.

PLACE OF WITNESS NO. 8.

Inspection made November 8, 1913.

The young apple trees on this ranch are in bad condition on account of the work of the woolly aphis, *Schizoneura lanigera* Hausm. I have never before seen trees so badly infested by this insect as these are. The roots, trunks, and branches of many of them are almost covered with these pests and many of the roots and branches are badly swollen and knotted. Trees in such condition can not be expected to flourish. Many of these same trees are also badly infested with the rosy aphis, *Aphis sorbi* Kalt.

The apricot and peach trees are in fairly good condition.

The almonds look well except for the work of the mites, *Bryobia pratensis* Garman. These have made the leaves look pale. Some of these trees show considerable gummosis, and a few black scales were found on others.

The plum trees seem to be in fairly good condition except for the work of the aphis-*Hyalopterus arundinis* Fab., which have curled some of the leaves and secreted a con, siderable amount of honeydew, in which the black, sooty mold is developing. This is, of course, responsible for the black condition of these trees.

The pear trees seem to be in good condition and free from insect pests.

The vineyard is in very good condition except for the vine leaf hoppers, *Typhlocyba comes* Say.

The red spiders, *Bryobia pratensis* Garman, have spotted some of the leaves on the quince, but these are not bad.

A few red spiders were also found on the cherry trees.

The young orange trees near the house are practically black from the sooty mold that is growing in the honeydew secreted by the black and soft brown scales that are abundant on these trees.

The berry vines show much spotting on the leaves, due to the work of the grapevine leaf hopper.

PLACE OF WITNESS NO. 23.

Inspection made November 8, 1913.

In the young orchard the cherry trees are fine, bright, and clean. Only a few red spiders were found on them.

The peach trees are in good condition. A few twig borers, *Anarsia lineatella* Zell., were found on them, and these will, of course, kill some of the new shoots next spring. Few red spiders were found on these trees.

On the old pear trees a considerable number of greedy scales, *Aspidiotus rapex* Comst., and a few black scales were found. There were enough of the latter to cause some blackening of the tree.

The old plum trees were badly infested with red spiders and black scale, and so, of course, were quite black.

The apple trees are in good condition, except that the leaves are whitened by the work of the red spider and a small leaf hopper. Some woolly aphis and rosy aphis were also found on these trees.

The old pear trees in the back yard are no longer cared for and are used for chicken roosts. The blister mite, *Eriophes pyri* Pgst., was bad on some of them.

PLACE OF WITNESS NO. 4.

Inspection made November 1, 1913.

The old orchard back of the house, consisting of 24 trees of various kinds, has evidently been abandoned, and is now used as a pasture for horses, cattle, and sheep.

The trees are badly broken and scarred and many of them are badly gnawed by the stock.

The apple trees are literally covered with oyster-shell scale, *Lepidosophes ulmi* Linn., and woolly aphis, *Schizonema lanigera* Hausm.

The pear trees have a good deal of black scale and greedy scale, *Aspidiotus rapex* Comst., on them. Mr. Brazil stated that the pears and apples are full of worms, a condition that we would expect.

The orchard is of no commercial value in its present condition, and no estimate could be made of the amount of damage due to any cause.

PLACE OF WITNESS NO. 12.

Inspection made November 8, 1913.

The almond trees along the roadside are in fine shape. They are clean and almost free from red spiders and black scale.

The peach trees, too, are clean and bright, but there are few of the peach-twig borers, *Anarsia lineatella* Zell., in them.

The plum trees at the upper end of the orchard have considerable black scale; hence they are black from the sooty mold. The aphis, *Hyalopterus arundinis* Fab., and the two-spotted mite, *Tetranychus fimaculatus* Harv., are still rather abundant on some of these plum trees.

The apple trees have a few woolly aphis, rosy aphis, and oyster-shell scales, but they are doing no appreciable injury.

The apricot trees are in good condition.

The small orange trees are badly infested with brown scale; hence the leaves, trunks, and limbs are badly affected with the black, sooty mold.

The grapevines are in fine condition, except for the work of the grapevine leaf hoppers.

On the whole, this little orchard and vineyard is in as good condition as one would find anywhere in the State, and I have often called attention to it as an example of what one is able to do in this section if the proper care is given to the orchard.

PLACE OF WITNESS NO. 32.

Inspection made November 14, 1913.

The small grove of orange trees on this place is in bad condition. Nine of the trees show little green wood and the rest of them are in little better condition. Those nearest the house are in the best condition. The tenant explained this by pointing out that the house was between these trees and the point from which the smelter smoke usually came. This was considered strong evidence that the smelter smoke was responsible for the death of the other trees, but the fact should be noted that these same green trees are the ones that have received some water, while the others have evidently received none. A pipe was used to lead the water some distance from the tank house, and the water was then carried in small ditches to these green trees. Some of the trees have also been dug around. There is nothing to indicate that the nine or ten trees that are in worse condition have received any water or cultivation. I find that roots of considerable size have come near to the surface of the ground, many of them being within 5 or 6 inches. This shows that there has been no recent cultivation.

All of the trees show about the same amount of black scale, *Saisseta oleae* Bern., brown scale, *Lecanium corni* Bouche, and cottony cushion scale, *Icerya purchasi* Mask., and all are equally black as a result of the sooty mold. The scale insects are not abundant enough to account for the poor condition of the trees.

The thrifty condition of the young trees in Corcoran's yard just across the road, which have absolutely no protection from the smelter smoke should it come in from the direction indicated, leads one to believe that the condition of the trees in this orchard can be due to nothing but neglect.

The lemon trees look little better than the orange trees, and the conditions surrounding them are about the same.

The pomegranate trees have some black scale and a few cottony cushion scales, and consequently show some of the black, sooty mold.

The rose bushes and other ornamental plants in the front yard are now being pruned. The amount of old wood that is being removed shows that this is the first pruning they have had for some years.

Four grapevines that are climbing over the exposed side of the house—that is, the side toward the gap in the hills through which the smelter smoke is said to come, are in good condition and still have some grapes on them.

The olive trees have some fruit on them, but they are quite black with the sooty mold, which is due to the presence of black scale.

Scale insects are also very abundant on the holly trees. These trees are, therefore, very black with the sooty mold.

The old vines in the small vineyard are almost leafless now. The remaining leaves show that there have been some leaf hoppers at work on them. These vines have been cultivated and seem to be in good condition.

The old apple trees are badly infested with San Jose scale, *Aspidiotus perniciosus* Comst., and oyster-shell scale, *Lepidosaphes ulmi* Linn. I have seen no other trees in this region so badly infested with these insects. There are also some rosy aphis, *Aphis sorbi* Kalt., and woolly aphis, *Schizoneura lanigera* Hausm., on these trees.

The plum trees are black on account of the presence of black scale and aphis.

PLACE OF WITNESSES NOS. 65 AND 75.

Inspection made November 14, 1913.

The place is situated on the west edge of Benicia.

A few old almond trees in this yard are uncared for and in bad condition. Some of them are quite black with the sooty mold that grows in the secretion from the aphis and scale insects. Witness No. 75 is sure that this black condition is due to smelter smoke. She says that it is over the stubble and everything else in the summer. She says that it is worse here in July and August.

The few fig trees in the orchard are also neglected and in bad condition.

PLACE OF WITNESS NO. 69.

Inspection made November 7, 1913.

The place is situated in West Benicia along the Vallejo Road.

The peach trees in this yard look fine and thrifty. No insects were found on them.

The apple trees too are looking fine. Only a few aphis were found on them.

The plum and pear trees also are in good condition.

This little orchard is well tilled and seemingly well cared for.

In the vineyard on the hill I found several places where the vines have made little growth this year. Others near them appear to be in good shape. This condition is probably due to either phylloxera, *Phylloxera vastatrix* Planchon, or to differences in the character of the soil. I dug around the roots somewhat and found no phylloxera, although closer search during the summer time might have revealed them. It is rather likely, however, that the condition of the vines in these spots is due to the differences in the soil conditions.

The leaf hoppers, *Typhlocyba comes* Say., are abundant in this vineyard and have done considerable damage this year.

PLACE OF WITNESS NO. 46.

Inspection made November 1, 1913.

The place is situated in West Benicia.

The apple trees in this yard are in very bad condition, due to the woolly aphis, *Schizoneura lanigera* Hausm., on the roots, trunks, and branches. The rosy aphis, *Aphis sorbi* Kalt., is also abundant on the leaves.

The pear trees still have a few leaves left on them and these are badly infested with the two-spotted mite, *Tetranychus bimaculatus* Harv.

The plum trees are also badly infested with the two-spotted mite and some black scale. These trees show a considerable amount of the black sooty mold. Some of these trees were injured by having a band of tar painted around the trunk about four years ago. The injury due to this treatment is still evident.

The peach trees have a considerable number of two-spotted mites on them.

The grapevines show conspicuously the work of the leaf hoppers, *Typhlocyba comes* Say.

The apricot trees appear to be in good condition. They have only a few scale insects, *Lecanium corni* Bouche, on them.

The leaves of the big blue plum tree are nearly all gone now. Those that remain show an abundance of two-spotted mites.

On this date the first rain of the season began.

PLACE OF WITNESS NO. 135.

Inspection made November 7, 1913.

The place is situated in Benicia one block east of the Benicia-Vallejo road.

Near the house there are about 150 grapevines, which we would estimate to be about 4 years old. These show many dying leaves, which are probably dying on account of the lateness of the season. A few grapevine leaf hoppers, *Typhlocyba comes* Say., were found on these vines.

The peach trees, which are 2 to 4 years old, are in good condition. No insects were found on them.

The one small plum tree showed many red spiders, *Tetranychus bimaculatus* Harv., and a few aphis *Hyalopterus arundinis* Fab.

The small lemon tree and the three small orange trees showed many cottony cushion scales, *Icerya purchasi* Mask., and soft brown scales, *C. hesperidum* Linn.

PLACE OF WITNESS NO. 9.

Inspection made November 7, 1913.

The old pear trees on this place are in bad condition. Some of them have large limbs that have been killed by a borer that has girdled the limbs and then entered the hardwood. The work looks something like that of the carpenter worm, but I am not sure what insect it is that has been doing the work.

A few blister mites, *Eriophes pyri* Pgst., and greedy scales, *Aspidiotus rapax* Comst., were found on these trees.

The apricot trees are badly infested with black scale, *Saisseta oleae* Bern., and hence are badly covered with the black sooty mold.

The apple trees are very badly infested with oyster-shell scale, *Lepidosaphes ulmi* Linn. This insect is probably in a large measure responsible for the condition of these trees. Rosy aphis, *Aphis sorbi* Kalb., and woolly aphis, *Schizonema lanigera* Hausm., are also bad on these trees.

The almond trees are badly infested with black scale and have much of the black sooty mold on them. Red spiders, *Bryobia pratensis* Gar., are very abundant on the almond trees.

The grapevines have been badly injured by leaf hoppers, *Typhlocyba comes* Say. which are still abundant on them.

PLACE OF WITNESS NO. 10.

Inspection made November 7, 1913.

Witness No. 10A says that the vineyard by the house is the oldest one in Benicia. They have given this vineyard good care during the four years they have been on the place, and she says they have always had a good crop of grapes.

She says that the trees in the yard have also yielded them good crops, because they have cared for them.

She says that the smelter smoke is sometimes strong enough to make her cough, but she does not think they have had any injury to the vegetation since they have lived there.

PLACE OF WITNESS NO. 24.

Inspection made November 15, 1913.

Witness No. 24A believes that her place has been badly injured during the past few years by the smelter smoke; practically nothing has escaped injury from it; the grapevines, fig trees, roses and other ornamental plants, all of the orchard trees, the wire fences and screens, and even the chickens and live stock, she believes, have been injured.

She showed me the remains of a chicken gizzard and liver that she says were perfectly black when the chicken was killed.

The lemon tree in front of the house is in fairly good condition. It has some soft brown scale, *Coccus hesperidum* Linn., and some cottony cushion scale, *Icerya purchasi*

Mask., on it. She says that she watches this tree carefully to keep the insects off and to keep it clean.

Two small orange trees in front of the house are very badly infested with soft brown scale and the leaves and trunks are covered with the black sooty mold. Witness No. 24A believes that this sooty mold is due to the smelter smoke.

The loquot trees are now blooming and in very good condition.

The peach trees are badly infested with black scale, *Saisseta oleae* Bern.; hence they are blackened with the sooty mold. The branches and some of the leaves are well covered with this black mold. Witness No. 24A says that the fruit was quite black last summer. She believes that smelter smoke was responsible for this condition.

The black sooty mold was probably growing on the fruit as well as on the leaves and branches.

Some of the brown apricot scales, *Lecanium corni* Bouche, were also present on the peach trees.

The plum trees were badly infested with black scale, and so were covered with the black sooty mold.

The south, or exposed, sides of the trees are badly sunburned and the wood thus injured is now infested with flat-headed borers, *Chrysobothris femorata* Fab.

The apricot trees are badly infested with black scale and show considerable black sooty mold on the leaves and branches of the trees.

The south sides of the trunks of the cherry trees are in bad condition. Most of these trees show considerable gummosis. Many of the upper twigs are dying.

The trunks of the apple trees are badly sunburned on the exposed side, and flat-headed borers are working in these affected places. Some woolly aphis, *Schizoneura lanigera* Hausm., and oystershell scales, *Lepidosaphes ulmi* Linn., were found. The latter are bad on some of the trees. Some of the leaves that remain on the trees are also affected by rosy aphis, *Aphis sorbi* Kalb.

In other parts of the report I have discussed the experiments that were made in this orchard to try to control some of these pests.

The old vineyard north of the house is in bad condition. It has not been cared for for some years because it has been unproductive. The vines in this old vineyard are dead in spots. The vineyard looks very much as though it had been affected some years ago by phylloxera, *Phylloxera vastatrix* Planchon. These insects gain a foothold in certain parts of the vineyard, sometimes entirely killing the affected vines, and at other times weakening them to such an extent that, although they may still remain alive, they are unproductive. The insects gradually spread through the vineyard and often affect all of the vines.

The younger vineyard west of the old one is in better condition, but the vines in the lower part of this vineyard are also dying. I tried to dig around these vines in order that I might examine the roots, but the ground was so hard that I could not dig more than 6 inches with a shovel. In this distance I found no small rootlets.

On January 9, 1914, after we had had a good deal of rain, I again dug around these grapevines in the young vineyard. I selected two vines that showed a little growth last year. No small roots were found on these vines and the large ones were mostly dead. I selected a vine in the old vineyard that showed as much growth as any near by, and no small roots were found on this vine, although we dug considerably more than 2 feet deep. The larger roots were nearly dead here also and although we found no root borers there was considerable evidence that these insects had been at work on the roots. On the roots of other vines in this vineyard we found a number of phylloxera.

The condition of the roots and the finding of these insects justifies my conclusions that the vineyard has been seriously affected by the phylloxera.

PLACE OF WITNESS NO. 26.

Inspection made November 21, 1913.

The olive trees on the hill back of this place are badly infested with black scale, *Saisseta oleae* Bern.; hence they are black with sooty mold. The trees are low, bushy, and not well cared for. There is little or no fruit on them.

The pear trees and the plum trees near the house are badly infested with European pear scale, *Epidiaspis pyricola* Del Guercio. Some of the trees in this orchard are dead and they were probably killed by this scale insect.

On February 14, 1914, I sprayed two plum trees and two pear trees in this orchard with distillate emulsion, using 1 part of the emulsion to 16 parts of water.

A later examination showed that although many of the scale insects had been killed, others were so well protected in the crevices of the bark that they had escaped the action of the spray material.

AGRONOMIC AND SOIL CONDITIONS IN THE SELBY SMOKE ZONE.

By Charles F. Shaw and E. E. Free.

INTRODUCTION.

In accordance with the instructions of the commission, we have made a study of soil conditions in the area under examination by the commission, the results of which study we report herewith.

In our letter of December 1, 1913, to the commission, we stated that in our opinion two separate problems were involved in the agronomic inquiry, namely:

1. Has the damage, or any part of the damage, claimed been due to some soil trouble not connected with the smelter?

2. Has there been any actual pollution of the soil of the area by materials from the smelter?

In the same letter we recommended the appointment of an assistant who should observe weekly the agronomic conditions in the region and report the occurrence and nature of any evidence indicating soil trouble or other circumstances injurious to the growing crops. We also recommended the analysis of a series of soil samples for elements, the presence of which would indicate soil pollution by smelter materials. Both recommendations having been approved by the commission, the investigations mentioned have been carried out and the results are reported herewith. The weekly examination of the region was made by Mr. Ralph W. Brown, whose detailed report appears herewith. The chemical analyses for the determination of soil pollution have been made by Mr. C. E. Brandt under our supervision.

AGRONOMIC CONDITIONS.

The soils of the region are loams or silt loams derived from the weathering of sandstones and shales extensively exposed in the region. There is little or no river silt or other soil material transported from a distance. The topography is between what would be called rolling and what might be called mountainous. Low but fairly steep hills alternate with narrow valleys, the lowest parts of which are frequently occupied by arms of the bay or by flat flood plains which were once estuaries and have been filled with alluvium.

The soils of the hillsides and hilltops are residual in origin and usually rather thin with frequent exposures of the underlying rock. Even in the valleys the soils are not deep, but are underlain at 2 to 4 feet by impervious clays. Humus is usually deficient even in the valleys, and is almost always so in the soils of the uplands.

The soils can not be regarded as of high quality. Their local origin from sedimentary rocks makes for lack of diversity in their mineral constituents and for poverty in plant-food materials. The low humus content, though perhaps in part susceptible to improvement by proper culture, is nevertheless a serious detrimental factor at present.

The chief disadvantage of the soils is their lack of depth. This decreases their capacity for water storage and for the supply of plant food materials to roots and, in connection with the steepness of the hillsides and the broken topography, renders proper cultivation and the accumulation of humus difficult.

No evidences of alkali or bad drainage have been observed except on the tidal flats in the lowest parts of the valleys, these flats being of small area and not under cultivation.

The agriculture of the region is largely the raising of grain (wheat, oats, and barley), much of which is cut for hay. Much land is pastured or used for volunteer hay. There are a few orchards, vineyards, and vegetable gardens, but all are small and unimportant to a general survey. Cultivation methods and agricultural practices in general are careless and not well thought out. The preparation of the seed bed does not receive proper attention; seeding is imperfect and irregular; no care is taken to eliminate weeds; and in general small use is made of the practices of modern agriculture. Especially is this true of practices assisting the conservation of soil moisture. There can be little doubt that on most of the soils of the area it is lack of water that limits production. The annual rainfall is only 15 to 20 inches and is not distributed satisfactorily through the year. The natural water-storage capacity of the soils is low. Accordingly the first essential of a proper agricultural practice for the region would be the effort to retain and conserve for crop use the largest possible proportion of the rainfall. Cultivation for increased absorptiveness, the increase of humus to improve capillary retention of water, the use of the soil mulch to prevent loss by evaporation; these and similar well-known procedures should be the backbone of the agricultural régime. We have not found them. So far as we can learn, this very important matter of water conservation has been entirely neglected by the farmers of the region.

The first question that our inquiry was intended to cover is noted above as the possibility of the damage claimed having been due to

some soil trouble. Excluding injuries affecting persons or domestic animals, the damage claimed is of two classes:

1. The so-called "visible" damage or "burning" of useful plants by gases or other poisonous materials from the smelter.

2. The "invisible" damage, a general detrimental effect on the amount and quality of the crop without the production of any definite injury of the "visible" class.

"Visible" damage is quite characteristic and is most unlikely to be confused with any effect of soil deficiency or other general trouble. Whether or not damage of this class occurs in the area examined is a matter outside the scope of our inquiry and to which we have given no attention. We are not acquainted with any soil-caused condition of plant unhealth which could possibly be mistaken for smelter injury of the visible class.

The existence of "invisible" damage in the region has been claimed on the ground of poor crop yield, unhealthful condition of trees, and the like. We have been unable to procure any satisfactory quantitative data of average yield, but it is beyond question that yields are below what would be expected for the climate of the region. This might be due to one or more of three causes: (1) Poor soil; (2) poor agricultural practices; (3) some definite unfavorable factor, such as damage by the smelter. In our opinion there is no doubt that the first two are operative and are adequate to explain the existing bad conditions. The soil is not good and the agricultural practices are such as to emphasize rather than to cure the natural soil defects. So far as we can judge from the experience of this year the crops have been at least as good as could be expected and there is no evidence of any "invisible" damage unaccounted for by soil and cultural deficiencies. Similarly in orchards and vineyards the unhealthful conditions that undoubtedly do prevail can be ascribed entirely to lack of intelligent pruning and cultivation, failure to provide against the inroads of insects and disease, and similar matters which may be summed up as lack of care. We have found no orchard trouble that can not be accounted for as due to this or to a naturally poor situation with regard to topography or soil.

It should be noted, however, that the past year has been unusually favorable as regards temperature and rainfall, and it is possible that injuries that appeared in previous years have not persisted or reappeared in this. We can say nothing as to this, and we do not attempt a final conclusion that damage by the smelter has not occurred, even in this year. All that we can say is that the poor agricultural conditions observed by us during the past fall, winter, and spring are amply accounted for by the naturally unfavorable soil and the extremely poor agricultural practice of the region.

SOIL POLLUTION.

The second problem presented us was that of discovering whether the material discharged by the smelter had contaminated the soils of the area under examination. The materials discharged are mainly of two classes: (1) Gases and condensable vapors, mainly the oxides of sulphur; (2) solid flue dust, consisting of compounds of lead, arsenic, and other elements.

Injurious soil contamination by materials of the first class is scarcely possible. In contact with water or moist materials the sulphur gases form either sulphurous acid or sulphuric acid, both of which would combine immediately with the hydroxides and carbonates always present in the soil, forming sulphites or sulphates of calcium, iron, magnesium, etc. Under soil conditions any sulphites so formed would not persist, but would be changed very rapidly to sulphates, which are normal soil constituents. In most soils calcium carbonate is the base, present in largest amount, and with which the sulphur acids would thus combine, the final result being calcium sulphate or gypsum.

Gypsum is somewhat more soluble in water than is calcium carbonate, and it is conceivable that the application of large amounts of sulphur gases to a soil naturally poor in lime might convert all of the lime into gypsum and thus increase leaching to an extent that would leave the soil really deficient in the essential lime salts. Indeed, actual cases of such injury have been reported from Germany.[a] In the present case such injury would seem improbable because of the distance of the smelter from the soils in question, but to make this conclusion certain, nine of the soil samples collected for the lead and arsenic determinations below described have also been analyzed for their content of calcium carbonate, with results as given in Table 1. The locations from which the samples were taken are given in a subsequent section of this report.

TABLE 1.—*Results of determinations of calcium carbonate in certain soils.*

Sample No.	Calcium carbonate.	Sample No.	Calcium carbonate.
	Per cent.		*Per cent.*
102	0.29	1302	0.16
302	.11	1402	.09
502	.18	1602	1.53
902	.04	2302	.10
1202	2.22		

The amounts of calcium carbonate found are as large as is normal for soils of the type and region, and calcium carbonate is present in all of the samples examined. This is really the important point, since damage by sulphur gases in the manner described would result in the removal of all the calcium carbonate by its transformation

[a] Weiler, A., (The removal of lime from soils through smelter smoke): Wiener landw. Ztg., vol. 63, 1913, p. 135; Eicke, (Damage from smoke in the Rhenish-Westphalian district): Rauch und Staub, vol. 3, 1913, pp. 162-167.

into gypsum. We may conclude that there has been no important damage to the soil by sulphur gases. Of course, this refers only to damage to the soil itself. Possible injury directly to the plant by sulphur gases in the atmosphere does not come within the scope of our investigation.

To discover whether there has been contamination of the second sort; that is, by flue dust, we have resorted to the determination of arsenic and lead in the soils. Except the sulphur acids, these are the only major constituents of the smoke that could be expected to have any poisonous action on plants; they are normal soil constituents only in traces, if at all; and lead is the chief metallic element in the fume and flue dust from the Selby smelter. These elements are well adapted therefore to serve as indicators not only of a soil pollution that might be agriculturally dangerous, but also of any lesser degree of contamination that, though not agriculturally injurious, would indicate the addition of smelter emanations to the soils of the area.

For the determination of these elements, soil samples were taken by A. E. Wells and E. E. Free at 24 locations, as shown in the list on page 413, and on Plate XXXVIII. (In pocket). At each station two. samples were taken; one of the surface half inch of the soil, the other, a normal soil sample taken in the usual manner to a depth of 10 or 12 inches. In all cases included rootlets were taken with the sample. The samples were taken between November 10 and 17, 1913, before the commencement of the winter rains, and thus included all dust accumulated during the summer but which might be removed by winter leaching. A slight shower fell previous to the collection of samples from stations 16 to 24, inclusive, but was scarcely sufficient to wet the surface and can have had no leaching effect.

The analytical methods employed in the examination of these samples have been worked out especially for this investigation. Arsenic had frequently been determined in soil by previous investigations and several methods have been described.[a] All are extremely complicated and laborious. Being desirous rather of discovering quickly the general indications offered by the arsenic content of the soils than of attempting perfect accuracy in the determination, we abandoned the complex methods of the literature in favor of a simple and rapid method, which may be outlined as follows:

A weighed sample of the well-mixed, dried soil was digested with sulphuric acid for several hours and soil and acid were then washed

[a] Gautier, A., Sur le dosage de l'arsenic, Compt. rend., vol. 122, 1896, pp. 426–427; Haywood, J. K., Injury to vegetation by smelter fumes, U. S. Bureau of Chem., Dept. of Agri., Bull. 113, 1908, p. 35; Mai, C., Nachweis und Bestimmung von arsen in Friedhoferde, Pharm. Zentralb., vol. 50, 1909, pp. 169–200; Headden, W. P., The occurrence of arsenic in soils, plants, and animals; Proc. Colo. Sci. Soc., vol. 9, 1910, p. 348; Bressanin, G., Methode de recherche, de séparation et determination de l'arsenic et de l'antimoine, Ann. chim. anal. vol. 17, 1912, pp. 81–84; Zuccàri, G., Ricerca e determinazione dell'arsenico nella terra di un cimitero, Gaz. chim. ital., vol. 42, pt. 2, 1912, pp. 633–638; Greaves, J. E., Some factors influencing the quantitative determination of arsenic in soils, Jour. Am. Chem. Soc., vol. 35. 1913, pp. 150–156.

into a Marsh generator of the usual type. The arsenic was collected as a mirror in a hard-glass tube in the usual manner and determined by comparison with standard mirrors produced by known quantities of arsenic. Care was taken to use reagents entirely free from arsenic and to make all mirrors under the same conditions of operation in all particulars. Comparative tests, tests on known materials, and the like showed this method sufficiently accurate for the purposes of this investigation.

The determination of lead was much more difficult. No method had been developed for small traces of lead in soil. The usual metallurgical methods are obviously inapplicable and the colorimetric methods employed in water analysis can not be applied in the presence of the complex and highly colored soil solutions. After much experimenting the following method was adopted:

Five hundred to 1,000 grams of the dry soil was digested, first with nitric acid, then with acetic acid and ammonium acetate. The double digestion is for the purpose of dissolving lead present either as metal, as sulphide, or as sulphate. After each digestion the soil was washed with water by decantation and on a filter. To the filtrate from the nitric acid digestion, potassium bichromate was added. The lead precipitated as lead chromate but in an impure condition. To purify it, the precipitate was dissolved in nitric acid and reprecipitated as lead sulphate by the addition of a little sulphuric acid. This precipitate of lead sulphate was dissolved in acetic acid and ammonium acetate and the lead precipitated with hydrogen sulphide, the sulphide being then dissolved in nitric acid and reprecipitated as lead sulphate. Usually it was necessary to repeat twice or more the purification by successive precipitation with hydrogen sulphide and sulphuric acid.

With the filtrate from the acetic acid digestion, the precipitation with potassium bichromate was omitted. The filtrate was treated directly with hydrogen sulphide and the precipitate purified by reprecipitation as sulphide and sulphate in the same manner as the precipitate from the nitric acid digestion. Both precipitates were finally weighed (separately or together) as lead sulphate.

The analytical results on the samples are given in Table 2. For convenience in the study of the table the soils are arranged in three groups according to location: (1) Those from the immediate water front and the sides of the hills facing the smelter, where full exposure to fume contamination would be found, if anywhere in the area; (2) those from behind the first range of hills, not directly exposed to winds from the smelter, and the exposure of which to fume contamination is possible but not certain; (3) those from beyond Sulphur Springs Mountain and from similar distant places where the smelter fume could scarcely be expected to reach in much quantity, if at all.

TABLE 2.—*Results of determinations of arsenic and lead in soil.*

[Parts per one million parts of dry soil.]

Character of samples.	Station No.	Arsenic or lead in surface half inch of soil.		Arsenic or lead in upper 10 inches of soil.	
		Arsenic.	Lead.	Arsenic.	Lead.
Exposed to fume contamination	1	2.0	21.5	3.0	5.4
	3	18.0	13.5	36.0	1.6
	4	30.0	11.5	.....	.....
	8	12.0	4.8	10.0	3.6
	9	16.0	5.9	6.0	4.9
	12	6.0	6.1	6.0	6.0
	13	5.5	12.9	16.0	4.2
	23	50.0	22.0	30.0	3.0
Exposure doubtful	2	2.0	7.1	8.0	3.4
	5	.....	.....	.4	2.4
	6	.....	.....	9.0	1.5
	7	.....	None.	10.0	None.
	10	.....	.....	20.0	4.8
	14	.....	.....	5.0	5.1
	15	.....	.....	40.0	None.
	24	.....	.....	12.0	6.4
Not exposed	11	8.0	10.5	3.6	6.8
	16	.4	2.2	6.0	.5
	17	.....	.9	4.0	None.
	18	.....	None.	8.0	.5
	19	.2	.3	7.0	4.9
	20	7.0	4.3	7.0	5.7
	21	.....	1.0	6.0	4.3
	22	.....	None.	4.0	6.8

Referring first to the arsenic determination, it is seen that this element was found in every soil examined, without exception. The quantities found in the more exposed soils are somewhat larger than in those of the less exposed groups, but the difference is not great and is no larger than the differences between samples of the same group. It is apparent that arsenic is a normal constituent of the soils of the region and that no conclusion concerning fume contamination can be drawn from the arsenic determination. This general presence of arsenic is quite in accord with the results of previous investigators. Small quantities of arsenic are of frequent occurrence in soil.[a] It has been found in many rocks, mineral springs and volcanic emanations, and in sea water. Clarke and Steiger[b] found it in composite samples of clay from the sea bottom of Mississippi River silt, and of igneous rocks from all parts of the United States. Few elements are more widely distributed.

[a] Orfila, —, Encore un empoisonnement par l'arsenic: Jour. chim. méd., vol. 5, ser. 2, 1839, p. 566; Becker, H., Ueber den Arsengehalt des angeschwemmten Landes in der Nähe des Wesergebirges: Archiv. Pharm., vol. 57, ser. 2, 1849, p. 129; Campbell, Dugald, On the presence of arsenic and antimony in the sources and beds of streams and rivers: Chem. News, vol. 3, 1861, p. 212; Sonnenschein, F. L., Ueber die Verbreitung des Arsens in der Natur: Archiv Pharm., vol. 143, ser. 2, 1870, p. 245; Schlagdenhauffen, —, and Garnier, —, L'arsenic du sol des cimitieres, au point de vue toxicologique: Compt. rend., vol. 100, 1885, p. 1388; Widtsoe, J. A., The relation of smelter smoke to Utah agriculture: Utah Agri. Exp. Sta. Bull. 88, 1903, p. 163; Gautier, A., Localisation de arsenic normal chez les animaux et les plantes, ses origenes: Bull. soc. chim. France, vol. 29, ser. 3, 1903, pp. 31–35; Headdon, W. P., The occurrence of arsenic in soils, plants, fruits, and animals: Proc. Colorado Sci. Soc., vol. 9, 1910, pp. 345–360; Greaves, J. E., The occurrence of arsenic in soils: Biochem. Bull. 2, 1913, pp. 519–523; Zuccàri, G., Sulla presenza dell' arsenico come elemento normale nelle terre: Gaz. chim. ital., vol. 43, 1913, pp. 398–403.

[b] Clarke, F. W., and Steiger, George, The relative abundance of several metallic elements: Jour. Wash. Acad. Sci., vol. 4, 1914, pp. 58–62.

Although this normal presence of arsenic in the soils renders it impossible to trace the arsenic found definitely to the smelter, it does not follow that no arsenic has been received therefrom. It is possible that the arsenic originally in the soil has been increased by a supply from the fume, but such supply, if any, has not been large, else the soils would contain much larger amounts than they do and the more exposed soils would carry substantially greater arsenic contents than those of lesser exposure. The amounts found are not larger than might naturally occur in the soil.

Turning to the lead determination, it is immediately apparent that this element is so frequently present as to strongly suggest that it also is a normal constituent of the soils. It was found even in samples from stations 19 and 20 miles away from the supposed zone of smelter influence. Unlike arsenic, lead has not previously been known to be a normal soil constituent, except in the neighborhood of metalliferous deposits. However, lead accompanied arsenic and other elements in the composite samples of deep-sea clay, river silt, and igneous rocks examined by Clarke and Steiger and noted above. It has been found in several samples of atmospheric dust [a] and in a number of rocks [b] and mineral springs,[c] as well as in the products of several volcanic eruptions.[d] It is not known to be so widely distributed as arsenic, but this may be due to failure to search for it and to the greater difficulty of its detection rather than to its absence.

Under the circumstances, possible error of the analytical results becomes important and requires discussion. Such error might consist in either (1) the mistaking of some other element for lead; (2) contamination of the sample with lead from utensils, impure reagents, or laboratory dust; (3) inaccuracy of results, due to loss of lead or to imperfect purification of the final lead sulphate precipitate.

To guard against the first of these errors—the mistaking of some other element for lead—the final lead sulphate precipitates from all the determinations were saved, combined, and the usual qualitative tests for lead applied. The reactions with potassium iodide and potassium bichromate, the behavior on charcoal before the blowpipe, and the electrolytic precipitation on the anode were all strongly and characteristically positive. Furthermore, the only elements at all

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[a] Hartley, W. N., and Ramage, H., The mineral constituents of dust and soot from various sources: Proc. Roy. Soc., vol. 68, 1901, pp. 97, 103-104.

[b] See Clarke, F. W., and Steiger, George, loc. cit.; also Clarke, F. W., Data of geochemistry, 1911, pp. 600-602, 643; and Lindgren, Waldemar, Mineral deposits, 1913, p. 414.

[c] See data and references cited by Pošepny, F., The genesis of ore deposits; Trans. Am. Inst. Min. Eng., vol. 23, 1893, pp. 223, 239-240; Clarke, F. W., Data geochem., 1911, pp. 173-197; and Lindgren, Waldemar, Mineral deposits, 1913, pp. 41-64, 89-93. See also Massol, M. G., Composition chimique des dépôts des eaux thermales d'Uriage (Isère): Bull. soc. chim., vol. 5, 1909, p. 404; Okamoto, Y., Minerals of Taiwan (Formosa): Beitr. Min. Japan, No. 4, 1912, pp. 157-188; and especially the extensive spectroscopic research of Bardet, in which he found traces of lead in all of 54 French mineral waters; Bardet, J., Étude spectrographique des eaux minerales françaises; Compt. rend., vol. 157, 1913, pp. 224-226.

[d] Dana, J. D., and Dana, E. S., System of mineralogy, 1892, pp. 165, 170; Hartley, W. N, and Ramage, H. loc. cit.; Campo y Cerdan, —, Ann. Soc. Espan. fis. quim., vol. 10, 1913, pp. 431-439.

likely to be present in large quantity in the soil and to contaminate the final precipitate are iron, aluminum, and the elements of the alkaline earth group. The combined lead precipitate was also tested for these. The sulphocyanate test showed the presence of a trace of iron, and the spectroscope disclosed a faint trace of barium. Calcium and strontium could not be found by the spectroscope and the delicate cobalt nitrate test failed to show any trace of aluminum or magnesium. Electrolysis of a solution made from the final precipitate left the cathode entirely blank, proving the absence of copper and other related metals. It may be considered certain that the material weighed as lead sulphate was actually that compound in at least a fair degree of purity.

To avoid possibility of the second error—accidental contamination with lead during the analytical process—every possible care was taken to procure reagents and utensils free from lead and to prevent its entry in dust from the air. Special reagents were used and all were carefully tested by blank tests. No dust-forming lead compounds were in use or handled in the laboratory during the work or for some time previous thereto. In addition, preliminary blank tests of a soil found to be free from lead were made, the method being used in all details. That these precautions actually were efficacious appears to be proven by the fact that some of the soils tested were found free from lead. Furthermore, it will be remembered that the method used included the double extraction of the soil, once with nitric acid and again with acetic acid and ammonium acetate. In most cases the filtrates from these two extractions were handled separately and the final lead sulphate precipitates from each were separately weighed. In 13 cases, one of these filtrates showed no lead, although lead was found in the other filtrate from the same sample. Six of these blanks were found on the nitric extraction and seven on the acetic. In all cases samples were handled in parallel groups of four or more, and in every case where no lead was found either in one filtrate or in both, lead was found in other samples handled at the same time, with the same reagents and utensils, and in the same way. It would appear that suspicion of accidental contamination with lead may be dismissed.

Concerning the third error—a possible numerical inaccuracy of the results—we are less certain. The analytical procedure is necessarily long and complicated. There is much chance both of the loss of lead and of the inclusion of small amounts of other substances with the final precipitate. Four preliminary tests, in which 10 milligrams of lead (in solution) was added to a lead-free soil and then extracted by our method, resulted in the recovery of 95 to 98 per cent of the added lead. This would indicate a fair accuracy for the method employed, but the tests are not sufficient in number nor sufficiently varied in character to afford entire assurance.

Further data in this connection are furnished by the results of duplicate determinations on certain of the samples. The data are given in Table 3.

TABLE 3.—*Results of duplicate analyses for lead.*

Sample No.	Lead (parts per million).		Sample No.	Lead (parts per million).	
	First analysis.	Second analysis.		First analysis.	Second analysis.
101	18.6	24.4	1301	25.3	0.6
301	23.4	3.6	1402	8.0	2.2
401	22.5	.4	1902	7.5	2.2
902	9.8	None.	2102	8.6	None.
1101	12.6	8.4	2202	13.4	.1

The agreement is far from satisfactory, especially since the second determinations are generally much lower than the first. It would seem possible that the first determinations were greatly in error because of contamination of the precipitate. Fortunately, some of the precipitates from these first determinations had been preserved unchanged. These were put again through the purification by alternate precipitation as sulphide and sulphate, with the results given in Table 4.

TABLE 4.—*Results of repeated purification of lead precipitates.*

Sample No.	Lead (parts per million).	
	Original weighing.	After repeated purification.
101	18.6	17.0
1101	12.6	15.0
2202	9.4	4.0
301 [a]	3.6	2.6

[a] Second analysis.

The agreement seems as close as could be expected with such small working quantities.

The discrepancies of Table 3 might be due to any one of three causes: (1) Too high results of the first determinations through contamination of the preciptates; (2) too low results of the second determination through loss of lead in the process of purification; (3) real differences in the lead content of the parts of the sample used for the two determinations. The third of these is a real possibility, especially if the lead found is a normal soil constituent. Lead normally present in the soil would probably occur as a comparatively important constituent of a few mineral grains. Its distribution in the soil mass would be anything but uniform. To take an extreme case, let us imagine it present as galena, a few grains of that mineral being

scattered through the soil. Repeated sampling of such a soil might show an extremely variable lead content, depending on whether the sample chanced to contain 10 fragments of galena, or 1 fragment, or none. It would not be possible so to mix such a soil as to obtain uniform aliquot samples. It is quite probable that something similar to this is the rule of occurrence of the minutest soil constituents, and discrepant analyses are quite to be expected.

However, we are unable to decide the real cause of the discrepancies of Table 3, and accordingly we can claim no great numerical accuracy for the data of Table 2. In our opinion it is more probable that lead has been lost in the analytical process than that the final precipitates were impure or contaminated with adventitious lead. Accordingly, we regard as the more reliable the higher rather than the lower of the discrepant results of Table 3, and, similarly, we regard the data of Table 2 as more likely to be too low than too high. Nevertheless, in making up Table 2 we have used the average of the determinations wherever more than one has been made on the same sample.

It will be apparent later that the unassurance of numerical accuracy in the results is not important practically. Allowing for all probable analytical errors, it can be considered certain that lead is present in the soils and that its amount is of the order of 10 parts per million, varying between zero and a maximum of perhaps 40 parts per million. All these values are so small as to have the same practical meaning.

There arises at once the question whether the lead may be regarded as a normal soil constituent or must be ascribed to fume or flue-dust contamination. It is not probable that smelter fume or flue dust would reach so far as the locations of the more remote soils in which lead was found, but it is not entirely impossible. In the effort to determine this matter, we have procured and analyzed several other soil samples from parts of the Coast Range far removed from the area in question. The results are given in Table 5. Samples A and B were collected by Mr. E. B. Watson, of the United States Bureau of Soils; samples 1,. 2, and 4 by Mr. J. W. Nelson, of the University of California; and sample 5 by Mr. J. A. Armstrong, also of the University of California.

TABLE 5.—*Results of determinations of lead in Coast Range soils.*

Sample No.	Description.	Lead, parts per million.
A	Near Ukiah; virgin soil from steep hillside	1.8
B	Near Ukiah; virgin soil from rounded hills	5.8
1	Southwest slope of Mount Diablo, near Danville; probably virgin soil	None.
2	Santa Clara Valley, 4 miles east of San Jose; virgin soil from hillside	None.
4	Santa Clara Valley, 4 miles east of San Jose; 1¼ miles southwest of Evergreen; virgin soil from valley floor	2.6
5	About 10 miles southeast of San Diego; black adobe from foothills	None.

It is nearly, if not quite, impossible that any of the soils represented in Table 5 had been subjected to industrial contamination. The fact that three of them showed no lead indicates that the quantities found in the other three were not due to analytical error or to contamination of the reagents, for the first five were treated exactly alike, run at the same time, and with the same lot of reagents. It appears, therefore, that minute amounts of lead may be normally present in Coast Range soils and it is quite possible that the lead found in the soils of the area under examination may be normally present in them and not in any way due to the smelter.

However, it will be noted from Table 2 that the soils of the more exposed group are slightly higher in lead than those of lesser exposure, and that the samples of the surface half inch are quite decidedly higher. In the light of the possible numerical inaccuracy of the results it would be unwise to ascribe much importance to this difference, but it seems sufficiently general among the samples to suggest a small amount of fume or flue dust contamination of the more exposed soils. It is apparent, however, that this contamination, if actual, has been very slight.

Our conclusions in the matter of soil pollution are as follows:

1. Arsenic is certainly a normal, though extremely minute, constituent of the soils of the region, and lead is probably so.

2. The past contamination of the soils by lead and arsenic from the smelter is possible but unproven and appears not to be susceptible of proof.

3. The quantities of lead and arsenic added, if any, have been small and of the same order as the quantities of these elements normally present in the soils.

In our opinion, the maximum amounts of lead and arsenic found are far too small to have any injurious effect on plants grown in the soils. Indeed, much larger amounts than those actually found would be without practical effect on the agriculture of the region. In this connection we refer to the opinion of Prof. C. B. Lipman, of the University of California, as given in his report on another page.

DATA REGARDING SOIL SAMPLES.

The stations from which samples were collected are numbered 1 to 24, inclusive, the locations being marked on the map comprising Plate XXXVIII. The numbers of the individual samples consist of the number of the station, followed by a zero, followed by a number designating the sample. Thus, 101 is sample 1 from station 1; 1202 is sample 2 from station 12, etc. In all cases sample 1 from a station is of the surface half-inch; sample 2 is the general soil to 10 or 12 inches, as noted elsewhere in this report. Thus, 101 and 1201 are surface samples from station 1 and station 12; 102 and 1202 are the general soil samples from the same stations. A description of the stations follows:

Station 1.

Brow of hill directly opposite Vallejo Junction and fully exposed to wind from smelter, about 1½ miles distant. From side of hill facing the bay and about 15 feet below crest of hill. Elevation approximately 190 feet. Used for pasture. Slope about 15° southwest.

Station 2.

Northeast slope of small hill directly northeast of station 1. Behind the first line of hills and not so directly exposed to fume. About 40 feet below top of hill on side away from smelter. Slope about 10° northeast. Elevation approximately 110 feet. Had been planted to grain in last season.

Station 3.

Southwest slope of high hill east of station 1. About 75 feet below top of hill and directly exposed to winds from the smelter. Slope about 18° southwest. Elevation about 225 feet. Used for pasture.

Station 4.

From bottom of a small slough leading westward from station 3 and into east side of small cove shown on map. Composed of material washed from the directly exposed slopes of the hills to the east, a drainage area of about one-third of a square mile. Slope about 2° down slough. Elevation about 25 feet. Not used agriculturally.

Station 5.

Top of low, rounded hill northeast of Carquinez cemetery. About 2 miles from the water front and separated therefrom by three rows of hills. Taken about 25 feet southwest of the county pesthouse (not occupied). Practically level. Elevation about 200 feet. Not used agriculturally.

Station 6.

Northeast slope of hill south of the place of witness No. 6, being on the first range of hills but on the side away from the smelter. About 50 feet below the top of the hill. Elevation about 250 feet. Slope about 20° northeast. Had been planted to grain in previous year.

Station 7.

South slope of hill carrying old well derrick on road to Glen Cove. About 30 feet below top of hill, but not exposed to downward drainage from derrick site. Is on the side toward smelter and fully exposed to winds from that direction, but two rows of hills intervene, both higher than location of sample. Slope about 12° south. Elevation about 275 feet. Apparently was planted to grain in previous year.

Station 8.

From bottom of Glen Cove about 50 feet west of slough and just north of village. Not directly exposed to winds from the smelter, but has probably received drainage and alluvium from the hills to the northeast, which are directly exposed. Slope about 2° south. Elevation about 50 feet. Used for pasture.

Station 9.

From west slope of hill back of Dillon Point. About 150 feet below top of hill on side directly toward smelter and fully exposed. Slope about 10° west. Elevation about 150 feet. Used for pasture, but apparently once planted to grain.

Station 10.

From foot of hill west of alluvial flat of Southampton Bay. Sheltered from smelter by range of hills to west. Receives drainage from these hills, but from their unexposed slope only. Slope about 5° east. Elevation about 20 feet. From edge of grain field, beyond planting, but has been pastured by stock.

Station 11.

About 1 mile north of Midway road house on road going north. Taken on east side of road on top of small hillock, not exposed to drainage. About 3 miles from water front and shielded from smelter by three rows of hills. Slope very slight. Elevation about 150 feet. Used for pasture.

Station 12.

From west end of hill on water front at northwest end of city of Benicia. Fully exposed to winds from the smelter. About 30 feet below top of hill. Slope about 9° west. Elevation about 75 feet. Used for pasture. This is from near the location of one of the dust catchers of the commission.

Station 13.

Point on water front in city of Benicia at location of commission's air analysis station. Taken from side of road. Fully exposed to winds from smelter. Very slight slope. Elevation about 15 feet. Not used agriculturally.

Station 14.

In hills north of Benicia as marked on map. On southwest slope of small hill, facing toward smelter but behind shoulder of hill. Slope about 9° southwest. Elevation about 450 feet. Planted to grain.

Station 15.

On hills northeast of Benicia (Pl. XXXVIII). Exposed to winds from smelter, but about 1 mile from water front. From southwest slope of small hill on crest of divide. Slope about 10° southwest. Elevation about 200 feet. Planted to grain.

Station 16.

From small hill on southwest side of valley of Sulphur Springs Valley Creek (Pl. XXXVIII). On top of small hill. Over 2 miles from water front in direction of smelter and protected by hills back of Benicia. No slope. Elevation about 120 feet. Planted to grain.

Station 17.

About 3 miles south of Cordelia and about 12 miles from the smelter, with many high hills between. From foot of the northeast slope of hills. Slope about 10° northeast. Elevation about 50 feet. Used for pasture.

Station 18.

At mouth of American Canyon, about 2 miles west of Cordelia. From low hills at north side of canyon. Apparently fully protected from winds from smelter. Slope about 8° east. Elevation about 250 feet. Used for pasture.

Station 19.

In American Canyon, near summit (Pl. XXXVIII). From top of hill north of road. Apparently fully protected from winds from smelter. Very little slope. Elevation about 500 feet. Used for pasture.

Station 20.

From foothills west of Sulphur Springs Mountain (see Pl. XXXVIII). Possibly exposed to winds from smelter coming up the Napa Valley (7 miles), but important exposure by this path is not to be expected, as winds seldom blow in this direction. From road side. No slope. Elevation about 115 feet. Not used agriculturally.

Station 21.

At the southwestern foot of Sulphur Springs Mountain, about one-fourth mile north of Sulphur Springs. Taken on southwestern side of a small spur of the mountain, not exposed to drainage from main ridge. Protected from winds from smelter by over 5 miles of hilly country. Slope about 10° southwest. Elevation about 400 feet. Used for pasture.

Station 22.

West of southern end of Sulphur Springs Mountain, at head of south branch of Sulphur Springs Creek. Protected from winds from smelter by about 4 miles of hilly country. At foot of slope leading to hills to the south. Very little slope. Elevation about 480 feet. Planted to grain.

Station 23.

Hill on northeast side of alluvial flat at head of Southampton Bay. Fully exposed to bay but somewhat protected against winds from the smelter by the hills back of Dillon Point. From hillside facing toward smelter (southwest). Slope about 15° southwest. Elevation about 100 feet. Planted to grain.

Section 24.

From top of hill in grounds of United States Arsenal at Benicia. Partly sheltered from winds from the smelter by the city of Benicia and the hills west. Very little slope. Elevation about 150 feet. Not used agriculturally.

LETTER OF PROF. C. B. LIPMAN CONCERNING INJURIES BY METALS IN THE SOIL.

Below is presented a letter by Prof. C. B. Lipman regarding injuries to vegetation caused by salts of the heavy metals in the soil:

SELBY SMELTER COMMISSION,
San Francisco, Cal.

GENTLEMEN: In accordance with the request of Messrs. Shaw and Free, I beg to submit a statement with reference to the results obtained in experimental work carried out in my laboratories and greenhouses on the effects of salts of the heavy metals on barley, wheat, and vetch.

Of interest particularly in connection with the investigations of Messrs. Shaw and Free are the figures obtained on the effect of lead on the growth of barley. In growing two successive crops on soil treated with lead sulphate we have found that no damage to crops occurs unless the plants be put in immediately after the lead sulphate is incorporated into the soil. Amounts as high as 1,000 parts of lead sulphate per million have been used in a soil plentifully supplied with organic matter, without any damage whatever to the crop. Indeed, stimulation of the crop has been obtained with very considerable concentrations of lead sulphate (in excess of 1,200 parts per million.

Similar results were also obtained with copper sulphate, which shows that the amount of organic matter or of colloidal material in the soil regulates the point of stimulation or toxicity of the salt in question. Thus, for example, in a very sandy soil barley growth was much stimulated by the presence of 100 parts per million of copper sulphate, and amounts higher than that in that same soil showed a gradual toxicity as the concentration became greater.

In an adobe soil the point of highest stimulation was between 300 and 400 parts per million of copper sulphate, and in the same kind of soil to which much organic matter had been added the point of highest stimulation was 700 parts per million. In any case, however, stimulation by the use of copper sulphate at some point had been shown to obtain so far as barley is concerned.

It is particularly to be noted also that the copper compounds used are not such insoluble ones as are likely to occur in smelter wastes, but is the copper sulphate, which is an easily soluble salt.

Similar results, differing only in degree but not in kind, were obtained with zinc sulphate and iron sulphate, the latter having been used in very much larger quantities than even the zinc or the copper.

Considering that the largest amount of lead found in the soils by Messrs. Shaw and Free was equal to 25 parts per million, it would seem that lead as a factor in the destruction of plants, through its content in the soil, or through the latter's contamination from smelter wastes, would seem to be absolutely a negligible one. None of the amounts of lead which we used in our investigations was as low even as 25 parts per million on the basis of the weight of the soil, lead sulphate being used, and yet no toxic effect, but actually stimulating effects, from quantities far in excess of 25 parts per million parts of lead were obtained.

So far as arsenic is concerned, I can not make any statement based on our own experiments, because, although we have some work started along that line, it is not com-

pleted, and therefore we are unable to make definite statements. It would appear, however, from the experiments of Greaves at the Utah Experiment Station, that the bacterial flora at least, upon which crops depend for their available plant-food supply are very active, and may be stimulated by quantities of arsenic which are certainly not smaller than those which have been found by Messrs. Shaw and Free in the soils about the Selby smelter.

I wish to offer it, therefore, as my opinion, based on extensive experimental work with the so-called poisonous metals that are likely to be thrown down in the smelter wastes and thus introduced into the soil, that no damage can possibly come to any appreciable area of land around the smelter from the deposition of poisonous metals through the fumes of the smelter. No content of these materials in the soil as yet determined has shown itself to be great enough in our experiments to give anything but a stimulating effect to the growth of the plant, and although the smelter problem may be a serious one as regards sulphur dioxide gas and its effects on crops, it has no significance at all so far as the solid smelter wastes are concerned which are introduced into agricultural soil areas through the smelter fumes.

Very truly, yours,

(Signed.) CHAS. B. LIPMAN,

Professor of Soil Chemistry and Bacteriology, University of California.

REPORT ON WEEKLY AGRONOMIC OBSERVATIONS.

By Ralph W. Brown.

INTRODUCTION.

The object of my work was to collect data on the agricultural practices in the district lying between Benicia and Vallejo, and extending from the water front inland one to three miles. Data were collected also on soil, crops, and climatic conditions in this territory.

The data were obtained by weekly observations, the entire territory being gone over at each time. General observations were made on the region as a whole and specific observations made and data kept on a number of typical farms, as is noted later. In making these observations I went out into the fields and noted the various agricultural practices as they were being carried on. Data were taken each week on the farms being watched specifically, and also on other farms when anything new happened.

GENERAL REMARKS ON OBSERVATIONS.

These observations were begun December 6, 1913, and carried on until April 29, 1914. The dates upon which observations were made were: December 6, 16, and 17, 1913; January 8, 17, 24, and 31, 1914; February 7, 14, 21, and 28, 1914; March 7, 13, 20, and 27, 1914; April 3, 10, and 29, 1914.

The weather during the period of observation was mild. There was practically no frost and yet, with the exception of the middle two weeks of March, there was no really warm weather. The wind blew a great deal, usually starting about 10 o'clock in the morning and lasting until evening. During rainy periods, the wind was always from a southerly direction, usually a little east or west of direct south. During clear weather the wind was practically always from the west. Fogs were common in the mornings during December and most of January.

On December 1, 1913, a rain gage was installed at the location of sample station No. 12.[a] The rainfall for the season preceding that

[a] See p. 464.

date was obtained from the Benicia Water Co., which has a rain gage in the same locality. The rainfall was as follows:

Time.	Inches.
Month of November, 1913	5.22
Dec. 1, 1913, to Jan. 3, 1914	4.97
Reading Jan. 8, 1914	.42
Reading Jan. 17, 1914	2.92
Reading Jan. 24, 1914	2.95
Reading Jan. 31, 1914	.52
Reading Feb. 21, 1914	2.68
Reading Feb. 28, 1914	.38
Reading Apr. 3, 1914	.77
Reading Apr. 10, 1914	.83
Total for season	21.66

So far as climate and rainfall conditions are concerned the season has been ideal for volunteer crops and slack agricultural practices. Poor agricultural practice would not show up nearly so markedly this season as in those of lesser rainfall.

The soil of the district as a whole is not very deep, 1 to 3 feet being about the average. Ninety per cent of the pole holes dug for a private telephone line along the road leading directly north out of Benicia and extending about three miles showed a clay or sandstone subsoil. In practically no case were the holes deeper than 3 feet, as only 4 by 6 inch poles were used. As a whole, the tillable soil seems to contain a large percentage of clay, as it packs and runs together to quite an extent after rain. The soil gives the appearance of having been derived from thinly bedded sandstone and shales.

The acreage under general observation was approximately 8,000 acres. Practically all of this land that is cultivated is used for grain, namely, wheat, barley, and oats. A great part of the grain is cut for hay. A great deal of the land is either pastured or allowed to produce a volunteer crop.

Summer fallowing is practically never used in this region, and I was unable to find a seed drill on a single farm.

There are also a few orchards and vineyards. The vineyards are quite well taken care of, being pruned fairly well, and cultivated quite thoroughly. The orchards, on the other hand, receive little or no care. In no case did I find any spraying, and in only few places any pruning, and where the pruning was done, it usually showed a lack of knowledge in this line on the part of the workmen. Also, the orchards receive little cultivation, and it is the usual practice to sow grain in them if they are cultivated.

The general method of sowing grain in this region is to plow to a depth of 4 to 6 inches with a moldboard plow, broadcast the seed on this, and harrow it in.

SPECIFIC OBSERVATIONS.

The detailed data recorded as a result of observations are presented below:

Place of witnesses Nos. 1 and 1A, 80-acre field.

Eighty just east of house and adjacent to county road. No summer fallow. Plowed with 2-horse moldboard plow. Planted first week of December, 1913, one-third to wheat and two-thirds to barley. Sown with broadcast seeder. Harrowed in. Not very careful work.

January 8, 1914.—Grain up about 2 inches. From this time on the grain grew normally for the district, but became foul with weeds. Not a good crop for a season like this.

Place of witnesses Nos. 1 and 1A, 40-acre field.

On water front. No summer fallow. Ground not cultivated before sowing. Planted December 16 and 17, 1913. Seed broadcast with seeder on last year's stubble. After seeding, land gone over with four-horse cultivator, which did not turn soil, but merely scratched the upper couple of inches. Cultivator followed by harrow.

January 8, 1914.—Grain up about one-half inch.

January 31, 1914.—Owing to shallow cultivation, heavy rains, and clay content, the soil packed rather hard. From this time on grain made poor growth and thin stand.

March 27, 1914.—Rolled with heavy four-horse roller. Grain so high and soil so hard that roller had no effect whatever on soil, but bruised the grain considerably.

April 29, 1914.—Seems to be poor crop.

Place of witness No. 139.

Eighty acres. Plowed part of place December 16 and December 17, 1913, using two-horse moldboard plow.

February 14, 1914.—Plowed a couple more days. Finished plowing during first week of March. Planted entire place to barley with broadcast seeder.

March 5, 1914.—The parts plowed about the middle of December, and on which weeds were thick, were sown with the rest, making a poor job. The broadcast seeder was followed by a harrow, which left much of the seed uncovered in the weedy parts, but did better work on parts plowed just before sowing.

March 13, 1914.—Grain just coming through. Afterward this grain came on about normally for the district, but was weedy in parts; plowed in December.

Place of witness No. 12.

Acreage approximately 250. One hundred and fifty left for volunteer this year. Remainder sown to wheat, barley, and oats. Part under specific observation, about 15 acres adjacent to county road, sown to oats.

December 16, 1913.—No summer fallow. Being plowed with three horses on single-bottom plow. Apparently doing good work.

February 4, 1914.—No work done since middle of December because of wet weather. Part plowed during December sown to oats by broadcasting. Harrowed in.

February 28, 1914.—Grain just coming through; scarcely visible in wet sections.

March 20, 1914.—Poor stand on sown ground, which witness says is due to large flocks of blackbirds present at time of sowing.

April 29, 1914.—Cutting volunteer crop. A fine stand.

Place of witness No. 11.

Approximately 100 acres. Summer fallowed. Plowed early part of December, 1913, with gang plows, to a depth of about 5 inches. Planted to wheat with broadcast seeder, followed by harrow, about the middle of December.

January 8, 1914.—Grain up a couple of inches and doing well. From this time on grain made a fine growth, but the Hessian fly caused a good deal of injury during the hot spell in March.

April 29, 1914.—A good crop expected.

Place of witness No. 4.

Approximately 200 acres. No summer fallow. Planted as fast as plowed.

February 14, 1914.—Partly plowed and planted. Plowed with gang and two-horse plows. Planted to oats with broadcast seeder, followed by harrow. Broadcast seeder used, so seed was distributed rather irregularly, overlapping in some places, and in others missing by a few feet, some places sowing heavy and others light.

February 28, 1914.—Part first planted just coming up. Remainder being worked.

March 7, 1914.—Planting finished.

March 20, 1914.—Grain up all over field. Other than being somewhat irregular, the grain looks good for having been sown so late, owing to late rains.

Place of witness No. 8.

Approximately 100 acres. No summer fallow. Plowed with two-horse plows. Planted mostly to barley with broadcast seeder. Harrowed in.

December 16, 1913.—Upper end being plowed.

February 14, 1914.—Part plowed about middle of December being sown. Remainder being plowed down to lower end where there was too much moisture. Sown as soon as plowed.

February 28, 1914.—Grain up about one-half inch.

March 13, 1914.—Some of the lower land that was too wet when the other was worked is being planted. This part was disked, broadcast, and harrowed in. The lowest part of field could not be handled even at this late date. From this time on the grain came along all right, but the part disked in the wet soil is pretty foul with weeds.

April 29, 1914.—Stand of grain rather thin. Claimed to be due to large flocks of blackbirds, which were prevalent in district at seeding time.

Place of witness No. 6.

Approximately 5 acres. No summer fallow. Plowed with two-horse plow, about March 8, 1914. Soil rather dry, turned up cloddy. Planted to barley by hand broadcasting, giving uneven distribution of seed. Harrowed in, but soil so cloddy that the surface was left rough and seed cover shallow.

March 20, 1914.—Grain up about an inch. From this time on grain came along all right, because of the fine distribution of rain relative to the time this crop was sown.

Place of witness No. 48.

December 16, 1913.—Trees and vines dormant. Not pruned or cultivated. Vegetables for this time of the year look fine.

January 31, 1914.—Vineyard pruned.

February 7, 1914.—Hoeing vegetables.

February 14, 1914.—Planting some more vegetables.

February 28, 1914.—Trees in bloom. Vegetables look good.

March 20, 1914.—Planting more vegetables.

April 10, 1914.—Cultivating vineyard. Plowing with one-horse plow, grubbing around vines and harrowing.

April 29, 1914. Cutting hay. Fair crop.

The approximate area of this place is 25 acres, distributed as follows: 5 acres to vineyard; 5 acres to fruit trees, this part being sown to grain; 10 acres to grain and 5 acres to vegetables. Some of the grain is used green and this land put into vegetables. Trees not pruned or sprayed.

Place of witness No. 20.

About 2 miles north of Benicia. Area approximately 10 acres. No summer fallow. Pastured last year. Cultivated with spring-tooth harrow middle of December, 1913. This did not turn surface well but merely harrowed it to a depth of 2 or 3 inches. Hand broadcasted to oats and barley after above operation and seed harrowed in.

January 8, 1914.—Grain up an inch or so but very weedy. From this time on the grain did only fair, and is foul with weeds.

Place of witness No. 17.

Area approximately 10 acres. Located just across the road from place of witness No. 20. Plowed with two-horse plow middle of December, 1913. Hand broadcasted to barley and grain harrowed in.

January 8, 1914.—Grain up an inch or so and not nearly so weedy as place of witness No. 20. From this time on grain did well for the district.

Place of witness No. 16.

Area approximately 200 acres. Summer fallowed. Plowed with gang plows middle of December, 1913. Harrowed before planting to oats with broadcast seeder. Harrowed after seeding.

January 8, 1914.—Grain up an inch and a half. From this time on the grain did exceedingly well and is remarkably free from weeds for the district. One of the best stands in the district.

Place of witness No. 35.

Located just across road from place of witness No. 16. Area approximately 60 acres. No summer fallow. Plowed with a gang and two-horse plow middle of February, 1914. Sown about end of month to oats with broadcast seeder. Not sown heavily.

March 7, 1914.—Grain up about half an inch. Just after the middle of the month when the grain was about 2 inches high, the entire field was rolled with four-horse roller. From this time on grain made fair growth, but is a thin stand.

April 29, 1914.—Practically no crop.

Place of witness No. 27.

Area approximately 100 acres. No summer fallow. Plowed first week of January, 1914, with gang plows. Planted to oats with broadcast seeder first week in February, 1914. Harrowed in.

February 28, 1914.—Grain up 2 or 3 inches. Looks all right. From this time on grain made good growth, but became rather foul with weeds.

Place of witness No. 39.

Area approximately 200 acres. One-half of each side of road. Summer fallowed. Well plowed with gang plows the first week of December. Harrowed after plowing. Planted to wheat on north side of road and barley on south side, with broadcast seeder. Harrowed in.

December 16, 1913.—Grain up an inch or so and shows a good even stand. From this time on grain made a fine, even growth, remarkably free from weeds. This is one of the best grain crops in the district.

Place of witness No. 136.

Situated on the high road running northeast out of Vallejo and about 2 miles from the town. It is the last level piece of land just before entering the hills. Area

approximately 50 acres. Plowed with gang and 2-horse plows, about second week of December. Planted to oats with broadcast seeder. Harrowed in.

January 8, 1914.—Grain up about 2 inches.

January 24, 1914.—This place receives much seepage water, as it lies directly at the foot of the hills. Lowest parts of field yellowish in spots owing to excessive moisture.

January 31, 1914.—Low spots still show signs of excessive moisture. Remainder of place doing fair.

February 28, 1914.—All signs of excess moisture have disappeared and grain has taken on its natural color. From this time on grain was doing fairly well, but became so foul with weeds that at last observation crop looked to be poor.

INVESTIGATION OF LIVE-STOCK CONDITIONS AND LOSSES IN THE SELBY SMOKE ZONE.

By C. M. Haring, in cooperation with K. F. Meyer.

INTRODUCTION.

REASONS FOR THE INVESTIGATION.

In September, 1913, the Selby Smelter Commission petitioned the director of the California Agricultural Experiment Station, stating that they were unable to obtain qualified assistants to make a veterinary survey of the region between Vallejo and Benicia and report the pathological findings in animals that might die in that region. As this commission is an impartial body, appointed by a court of law, it seemed desirable as a public-service project to assist the commission. At the request of Mr. Ralph A. Gould, the secretary of the Selby Smelter Commission, I was authorized by Dr. Thomas Forsyth Hunt, director of the California Agricultural Experiment Station, to cooperate with the Selby Smelter Commission.

POINTS TO BE INVESTIGATED.

In consultation with Mr. Gould it was decided to make a survey of the live-stock conditions in the so-called "Selby smoke zone," situated in Solano County between Vallejo and Benicia. I was especially directed by Mr. Gould to determine the cause of any deaths that would occur in live stock and to report the autopsy findings in detail.

PLAN OF ORGANIZING THE WORK AND METHODS OF PROCEDURE.

At my suggestion, Mr. Gould asked Dr. K. F. Meyer, D. V. M., professor of bacteriology and parasitology, to act with me in this investigation. We employed William La Grange to take a census of the live stock and report on the methods of care and feeding in the area alleged to be exposed to smelter smoke.

Mr. La Grange was especially qualified for the work on account of his extensive experience with live stock under California conditions. He is a graduate of the University of California College of Agriculture.

He made a census of the live stock on 30 ranches and established a card system for identifying and reporting the condition of each animal. He arranged with the owners to phone the veterinary office, University of California, in case any of the animals developed sickness

or died. Mr. La Grange made weekly visits to the smoke zone during November. After that the work of observation was continued by Raymond S. Adams, Santa Cruz, Cal. His observations were supplemented by occasional visits by Dr. Meyer and myself.

The following veterinarians have also assisted us at various times:

Chester L. Roadhouse, D. V. M., associate professor of veterinary science in the University of California.

Fred M. Hayes, D. V. M., assistant professor of veterinary science at university farm, Davis, Cal.

Fred J. Wood, D. V. M., late veterinarian for the bureau of agriculture, Philippine Islands.

Dr. Roadhouse, Dr. Wood, and I also had an opportunity to tour the Selby smoke zone on July 15, 1914, with the following eminent veterinarians:

Veranus A. Moore, M. D., D. V. M., dean of the New York State Veterinary College, Cornell University, Ithaca, N. Y.

H. C. Gardner, D. V. S., Anaconda, Mont., veterinarian for the Anaconda smelter.

John Ernst, D. V. M., 125 East Fourth South Street, Salt Lake City, consulting veterinarian for the International Smelting Co.

LIVE-STOCK CONDITIONS IN THE SELBY SMOKE ZONE.

The area covered by our survey of the region alleged to be exposed to the smoke from the Selby smelter included 32 farms and small places lying between Vallejo and Benicia.

Our observations were made on the following dates:

1913.

Oct. 28. Haring and Meyer performed autopsy at place of witness No. 11.
31. La Grange visited ranches.

Nov. 4. Do.
7. Do.
8. Two of the horses of witness No. 23 were taken to Berkeley.
10. Haring and Bell performed autopsies at place of witness No. 11 and at place of witnesses Nos. 1 and 1A.
Specimens delivered to Meyer.
18. Meyer and Haring performed autopsy at place of witness No. 6.
20. La Grange visited ranches.
22. Do.

1914.

Jan. 21. Adams visited ranches.

Feb. 7. Do.
14. Do.
23. Do.
24. Roadhouse and Hayes operated on horses of witness No. 23 at university farm, Davis. One was killed and larynx delivered to Meyer.

Mar. 7. Adams visited ranches.

Apr. 11. Do.
13. Do.

1914.

Apr. 17. Hayes and Adams visited ranches.
18. Adams visited ranches. Horse of witness No. 23 was returned to Benicia.
21. Hayes and Wood immunized hogs at place of witness No. 6 and visited several other ranches.
30. Adams visited ranches.

May 1. Do.
15. Wood and Adams visited ranches.

June 15. Roadhouse and Hayes operated on horse of witness No. 6 in San Francisco.

July 8. Haring visited ranches.
15. Haring, Roadhouse, and Wood, accompanied by Moore, Gardner, and Ernst, visited ranches.
18. Wood visited ranches.

During the period of this investigation of the live-stock conditions on the 32 places above mentioned, there were inspected 308 horses, 315 cattle, approximately 900 sheep, and about 500 swine. These figures represent the number of animals inspected in bands or herds at pasture, or in corrals or pens, and also include 283 horses which were carefully observed, attention being given to each individual. The average conditions under which these animals are kept may be summarized as follows:

HORSES.

So far as the land, forage, and climate are concerned, the region between Vallejo and Benicia would seem to be suitable for the raising of horses. With the exception of the frequency of unsoundness in wind, which is described later, the condition of the horses will average about the same as in the regions of this State that are agriculturally similar. However, with a few exceptions, the horses are mediocre animals, and most of them would be classed as ordinary farm stock of no particular breed, the adult animals ranging in weight from 900 to 1,600 pounds. Some of the horses have the appearance of being "Standard bred," but of recent years there has been no market for good driving horses, and I doubt whether the best of these would bring over $150 a head if put at auction. There are a few teams of medium heavy horses that might bring $400 to $500 a span. Many of the animals are either aged or young and unbroken and would be hard to sell at $75 a head.

Most of the horses, except those that are being used for general farm work or teaming on the roads, are turned out on pasture. In the late winter, spring, and early summer of this year the feed was abundant. Last fall the field feed consisted of dry grass pasture and stubble fields, and in a few instances marsh or tule land. During the winter many horses were put up in barns during storms and fed grain hay without grain. In the late fall and early winter some of the animals that had not been caught up and fed were very rough looking and in poor condition of flesh owing to lack of feed.

Several of the farmers still fear that injurious fumes are coming from the Selby smelter and for that reason some bring the more valuable horses into the barns at night, believing that they are thus protected.

There is an unusually large percentage of horses in the smoke zone affected with roaring, a condition caused by the paralysis of certain nerves in the throat. This we (Haring and Meyer) attribute to injury by emanations from the Selby smelter. However, we have not been able to find any case that has developed between March and July, 1914. A detailed description of the cases of roaring in horses is given on subsequent pages.

WORK STOCK.

When worked the main source of sustenance for the horses is grain hay without grain. Some owners supplement this with rolled barley.

BROOD MARES.

Some of the mares are worked up to within a short time of foaling and then turned out on pasture or stubble fields and allowed to run out with foals until weaning time. At the place of witness No. 6 two very old animals with the suckling colts were fed a mixture of brown sugar, rolled barley, and alfalfa meal twice a day and ran out on pasture the rest of the time.

YOUNG COLTS.

Young colts are allowed to run out the year round in stubble fields and grass pasture, being fed a little hay in stormy weather and allowed to get shelter under sheds in some instances.

The photograph reproduced as Plate XXXIX, *A*, was taken July 7, 1914. The colts belonged to witness No. 12. The view of their environment is typical of the average pasture conditions in South Solano County and the smoke zone.

CATTLE.

With the exception of the large dairy of witnesses Nos. 1 and 1A, there are comparatively few cattle in proportion to the size of the farms. This, however, can not be attributed to fear of their being poisoned by smelter fumes, as all of the cattle owners, with one exception, reported that they believed no losses had ever occurred in cattle from "smelter poisoning." Witness No. 1 claimed that possibly two of his heifers had been "smeltered" and gave me an opportunity to autopsy them. The post mortem examination proved that they were severely infected with tuberculosis. No indications of chemical poisoning could be detected. During the late fall and winter the condition of the stock cattle in the smoke zone was bad, owing to lack of feed.

On account of the dry year, the pastures were poor. On the largest dairy ranch about all the dry cows and heifers had to eat during December and January was a poor grade of oat straw. The milking cows are fed hay and at a few places they also get concentrates during the fall and winter. They are fed and milked in barns. During the spring and early summer the pastures furnish enough to insure a milk flow. The stock cattle run out on grass pastures and stubble fields the year around. In the fall and winter of unusually dry years, like 1913, it is necessary to feed a little hay or straw. Some of the cattle are pastured on low tule lands and swamps near the bay.

SHEEP.

The sheep graze in stubble fields and grass pastures the entire year. In some places they are corraled at night as a protection against dogs and coyotes. During the winter, I was told, it was necessary to feed a little hay during stormy weather. No recent losses attributable to smelter smoke were reported by any of the sheep owners.

HOGS.

On most of the farms there are only a few hogs and these are maintained largely on the refuse from the houses. Witness No. 137 feeds a large number of hogs on the by-products of their creamery at Benicia, supplemented with a certain amount of mill feed. No losses in hogs which we (Haring and Meyer) attributed to smelter smoke were reported by any of the hog owners.

OCCURRENCE OF ROARING IN HORSES IN THE SELBY SMOKE ZONE.

Between October 28, 1913, and July 18, 1914, twelve cases of roaring (hemiplegia or diplegia laryngis) have been observed in the Selby smoke zone by veterinarians of the University of California. Following is a description of these cases:

CASE 1.

Owner: Witness No. 6.

Location: Pastured on ranches rented by witness No. 11. Usually at ranch of witness No. 9.

Description: Aged bay mare with colt at side.

On October 28, 1913, Drs. Meyer and Haring and Mr. Wells went to one of the Selby Smelter & Land Co. ranches, rented by witness No. 11, to make a post mortem examination of a horse (see case N) that had died on October 24. The carcass was so decomposed that the post mortem gave little information worth recording.

While Drs. Meyer and Haring were working on the decomposed carcass the owner, who was working in an adjoining field, came,

A. YOUNG COLTS RUNNING LOOSE ON STUBBLE FIELDS AND GRASS PASTURE IN SMOKE ZONE.

B. HORSES IN SMOKE ZONE. ANIMAL FARTHEST TO LEFT IS "CASE 2."

C. MARE, DESIGNATED "CASE 4." PERSONS SHOWN, FROM RIGHT TO LEFT, ARE V. A. MOORE, H. C. GARDNER, JOHN ERNST, F. J. WOOD C. L. ROADHOUSE.

and later Dr. C. Massero, a veterinarian of San Francisco representing the Selby Smelting & Land Co., came over the hill. After cutting up and inspecting the decomposed carcass, we all went across the field to inspect the band of horses with which the dead animal had been pastured. Employees of witness No. 11 drove these past us and up a steep hill. The only one noticed to be abnormal in any way was the bay mare with a colt at her side which I recorded as case 1.

This animal, when exercised by running uphill, exhibited great difficulty in breathing and emitted a loud roaring sound in breathing, which, according to the owner, he had not observed in her before.

Following is a statement of the symptoms observed on this date:

SYMPTOMS OF CASE 1, OCTOBER 28, 1913.

The animal is rather thin, but the general appearance is healthy. After a short period of exercise the nostrils become widely distended and trumpet shaped. Respiration is labored, the inspiration sound being roughened and audible several yards distant. On galloping uphill inspiration sounds become very loud and strident, clearly audible at a distance of 100 paces; intercostal spaces sink in deeply on inspiration, making the ribs stand out with great prominence. She coughed several times with a wheezy tone. After two minutes' gallop severe dyspnœa developed, animal stumbled, made convulsive movements with neck and front limbs and would undoubtedly have fallen if exercise had been continued. On resting the symptoms rapidly diminished in intensity and to a person a few feet distant she showed no signs of unsoundness on standing at rest.

SYMPTOMS, NOVEMBER 7, 1913.

Animal was seen by Mr. La Grange. He reported that she was in thin condition, coughed, discharged from nostrils, showed labored breathing on slight exercise, and was about ready to die. Witness No. 11 told him that the mare belonged to witness No. 6 and that for about 18 months she had been on the ranches leased by witness No. 11. Previous to this it was reported that she had been in a runaway in San Francisco and after that had been shipped to this locality. Most of the time she had been at pasture on the place of witness No. 9. Previous to foaling she had been driven some. Until the latter part of October, 1913, no abnormal symptoms were observed by witness No. 11.

SYMPTOMS, NOVEMBER 10, 1913.

The mare died in the morning of this day and was opened by Drs. Haring and Bell. The parts of the carcass that were abnormal in appearance were taken to Berkeley and delivered to Dr. K. F. Meyer. Their description is given in his part of this report.

Field notes of Dr. Haring.

Following are the field notes taken by Dr. Haring on this date:

11 a. m. Witness No. 11 says mare has been on his ranches one and one-half years and that she is 6 years old. He sticks to this opinion in spite of evidence by the teeth that the mare is much older; objects to an autopsy until he can call his veterinarian, but finally consents since we have already opened the animal. The body of the mare is in the swamp northeast of the residence of witness No. 11, the mare having been moved here several days ago from the field where she was observed on October 28.

The skin is still warm, showing that the animal has just died. There are no external evidences of disease or violence. On dissecting the body and making a hasty examination, all organs and tissues appeared normal except the following:

The anterior lobes of both lungs were emphysematous.

The principal lobe of each lung contained in its inferior part a hepatized and gangrenous area about 6 inches in diameter. This was not sectioned, as we wished to keep it intact for Dr. Meyer.

The pleural cavity contained about 2 quarts of clear serum with some yellowish fibrinous exudate floating in it.

The heart surface was noticed to have numerous ecchymotic and petechial areas. There was some clear serum in the pericardial sac. The left ventricle of the heart and the anterior and posterior aortas, carotid, and axillary arteries contained a large antemortem blood clot.

The stomach was empty except for about 2 quarts of turbid water. A few small bots (gastrophilus equi larva) were attached to its walls.

(The lungs, heart, trachea, larynx, and part of the tongue were taken to Berkeley.)

Report of Dr. Meyer.

Report of Dr. Meyer is as follows:

On November 16, 1913, 5 p. m., Dr. Bell brought to the laboratory the respiratory tract, heart, and liver of a horse.

History of the specimen: Mare, owned by witness No. 6; pastured by witness No. 11 of Benicia; died November 10. Autopsied by Drs. Haring and Beil.

The anatomical findings were as follows:

The tongue is dark bluish; the larynx intensely reddened; the epiglottis presents marked ramifications. Both lateral pouches are filled with greenish-yellow exudate; the left side of the mucous membrane is more intensely reddened than the right. The left cricoarytænoideus muscles on comparison are flatter and lighter in color than the right; the larnyx is somewhat compressed from the left side; the left recurrent nerve is short (only 1 inch long), apparently somewhat darker in color, and flat. The right nerve, long, white, and soft. Thyroids are apparently normal; left somewhat smaller than the right.

The mucous membrane of trachea is covered by smeary, adherent, grayish-yellow, flocculent puslike material. There is marked injection and ramification of the lining. At the bifurcation of the trachea there is a brownish-yellow, frothy exudate. Also in the main bronchi similar brownish-black, fetid-smelling material is found. Mucosa is entirely covered by the exudate; when washed the membrane is slate colored.

A slight (compensatory) emphysema is found in left anterior lobe of the lungs. The pleura is infiltrated and gelatinous. Interstitiæ are distinctly gelatinous, and several foci of grayish discoloration are seen in the anterior part of the principal lobes. Some croupous pneumonic foci, the size of an apple, are seen in this region. These areas contain necrotic tissue of a greenish, smeary color and consistence. In another portion of the principal (left) lobe, a greenish discoloration indicates another cavity with necrotic contents. The connecting bronchi are filled with a yellowish-green exudate.

Throughout the left principal lobe the bronchi are surrounded by greenish discolored lung parenchyma. In the anterior lobe the interstitiæ are very large and bulging over the surface. These surround a yellow, gelatinous cavity, the size of a walnut, with brown-reddish, bad-smelling contents; the wall is fluffy and does not show any distinct wall. Several smaller cavities, surrounded by pneumonic foci of catarrhal character, are seen.

Throughout the right principal lobe the bronchi are filled with a purulent exudate.

Mediastinal lymph nodes are soft, enlarged, medullary on section. In some cortical parts, yellowish puslike areas are numerous.

Heart: Along the auricular groove is petechiæ and ecchymosis. On right ventricle are small hemorrhages and fibrous filaments. Blood fairly well coagulated, separated in chicken-fat clot and soft clot. Myocardium is fairly solid, but dry. Some areas are of yellowish discoloration. Valves are normal (blood culture from coronary artery).

Liver: Surface is covered with fibrous filaments. Several areas of soft yellowish color with central necrosis are in the middle lobe. Acini not very distinct; sections have a turbid, fatty color.

The blood culture revealed numerous cocci and bacilli which were not identified.

Anatomical diagnosis: Gangrenous pneumonia of both lobes of the lung, purulent bronchitis and tracheitis. Slight atrophy of the left side of the larynx; parenchymatous organs show signs of degeneration.

Cause of death: Septicemia due to gangrenous pneumonia, the latter being the result of aspiration of foreign bodies (food?) on account of disturbed function of the larynx and pharynx (probably neuroparalysis).

Microscopic examination of pieces of the recurrent nerves: Small pieces of the right and left recurrent nerves, which were taken as close as possible to the muscles, were fixed in formalin and sectioned, stained as usual, for connective tissue, myelin, etc. By comparison with normal nerves a slight increase of connective tissue with round cells around the bundles was noted; the number of bundles is reduced. The differences between the right and left nerves are not marked and in no way conclusive.

Epicrisis: Macroscopically, a distinct atrophy of the muscles of the larynx indicated a neuritis or neuro-degeneration of the innervating current nerve. The microscopic examination of a small portion of the nerve failed to reveal distinct advanced lesions. The affection is apparently of recent date and more along the line of disturbed function than marked anatomical alteration of the nerve structure.

CASE 2.

Owner: Witness No. 11.

Location: Place of witness No. 9, rented by witness No. 11.

Description: Iron-gray mare with two white hind feet; face white below forehead. Age, 4 years; weight 1,000 pounds.

Witness No. 11 reported that mare had been running at pasture for over a year. In the latter part of March, 1914, he had hitched her to a buggy and driven her about 12 miles. He observed that her respirations were abnormal.

Symptoms, April 21, 1914.

On this date she was examined by Dr. Hay ℥, Dr. Wood, and Mr. Adams. She was among a bunch of horses at pasture and it was with some difficulty that she was corralled. During this activity and after being caught she did not show abnormal respirations when the amount of exercise is considered, but when first starting to run had a short coughing spell. The owner stated that he had observed this coughing once before. The respiratory sounds over the trachea seemed to be somewhat coarser than the normal. According to Dr. Hayes there appeared to be a slight atrophy of the left superior laryngeal muscles.

SYMPTOMS, JULY 15, 1914.

She was observed by Dr. Haring and Mr. Nye at pasture with five other horses on the place of witness No. 9. On galloping across the pasture she coughed three times in a roughened wheezy way. Her nostrils dilated wider than any of the horses with her and remained dilated for several minutes after the canter, while the nostrils of the horses which had accompanied her showed no dilation.

REPORT OF DR. WOOD, JULY 18, 1914.

She was seen by Dr. Wood on this date. Following is his report:

After running in the pasture for a few minutes this mare showed dilation of the nostrils with rapid respiratory movements. This dilation of the nostrils was not noted in the other horses although they were subjected to the same amount of exercise. No cough noted.

The photograph reproduced as Plate XXXIX, *B*, was taken on the place of witness No. 9 July 8, 1914. The six horses belong to witness No. 11. The animal farthest to the left is case 2.

CASE 3.

Owner: Witness No. 6.

Location: Was known to be on the ranches of witness No. 11 until November, 1913, when she was taken to the ranch at Elliott Cove.

Description: Black mare, aged, weight about 1,000 pounds, wire cut on right front foot.

On November 10, 1913, seen at pasture at Elliott Cove ranch by Dr. Haring and Mr. La Grange. When at rest the mare appeared normal, but when driven up the pasture at a slow trot she developed a strident sound on inspiration that was typical of roaring. The nostrils became abnormally dilated and Dr. Haring was able to completely wind the animal in five minutes by running after her in the pasture. On palpation the superior muscles on both sides of the larynx were observed to be atrophied. The sounds continued after the animal had been cornered and brought to a standstill, but on reducing the size of the nasal openings by pressure of the fingers over the false nostrils the inspiratory sounds ceased, but began again on removing the pressure. Pressure on the larynx increased the abnormal respiratory sounds. After standing three minutes the sounds disappeared and the nostrils contracted to normal dilation. Pressure of the larynx between the thumb and fingers produced a fluttering sound during inspiration. Temperature, 100.8. Pulse and heart sounds normal. Lung tones loud but not abnormal.

OBSERVATIONS, NOVEMBER 18, 1913.

Mare reported to have been found dead.

OBSERVATIONS, NOVEMBER 20, 1913.

Autopsy performed by Drs. Meyer and Haring. The anterior lobe of the left lung was found to have several pockets containing food. Cause of death probably due to pneumonia, due to inhalation of food particles. For autopsy notes see the following report of Dr. K. F. Meyer.

Post-mortem report on the horse owned by witness No. 6.

November 20, 1913:

Medium nourished brown mare, about 16 years old; died on November 18, 1913. Cadaver placed close to the hole where the owner intended to bury it. The lower part of the limbs had been cut and the abdomen opened by the owner. The intestines were found in the burial place; most of the organs badly decomposed.

The lungs were examined as far as possible.

In the anterior part of the left principal lobe several cavities, varying from the size of a cherry to that of a nut, were found. Each cavity contained a liquid, dirty, brownish mass, which contained particles of feed (hay and grain). The surrounding of the cavities was solidified and mostly yellow reddish in color; distinctly granular. In the bronchi and trachea a considerable amount of greenish, granular, clumpy material. The mucous membrane dark black, thickened, and rough.

The larynx showed a distinct thickening of the mucous membrane, blackish discolored, and is covered with a clumpy, yellowish exudate; muscles soft and decomposed. Apparently the larynx is asymmetrical. The recurrent nerves are soft and discolored.

Anatomical diagnosis.—Gangrenous pneumonia, due to aspiration of food particles. Asymmetrical structure of the larnyx. Septicemia.

A histological examination of pieces of the recurrent nerves revealed only autolytic changes due to decomposition.

CASE 4.

Owner: Witness No. 23, Benicia.

Location: Ranch of witness No. 32, rented by witness No. 138.

Description: Bay mare; aged; weight about 975 pounds; white star and small white stripe in face, black stockings, white left front foot.

History: According to the owner and witness No. 138 this mare had been on the ranch of witness No. 32 for a number of years, and symptoms of unsoundness in wind had been present for several years and have gradually been growing worse.

SYMPTOMS, NOVEMBER 7, 1913.

Seen by Mr. La Grange. Although more suitable for a roadster, at present the animal is being worked in a plow team, it being possible to work her about four hours per day. Arrangements were made by Mr. La Grange to ship this mare to Berkeley, the owner to be paid $50 in case the animal is injured or killed.

SYMPTOMS, NOVEMBER 8, 1913.

Animal arrived in Berkeley. On examination by Drs. Haring and Meyer and Reed the following observations were noted:

General appearance healthy but rather thin. Mucous discharge occasionally from left nostril; submaxillary glands slightly enlarged. Breathing normal when at rest;

inspiration roughened when first trotted, later very labored inspiration and respiratory noise typical of roaring. After driving 4 minutes up hill respiration very labored and 44 per minute; active movements and abnormal dilation of nostrils, type of breathing costal abdominal, perspiration copious, labored locomotion. After 45 seconds' rest the strident respiratory sounds ceased. The conjunctival mucous membranes were slightly injected and became more so after driving. In the opinion of Dr. Meyer and Dr. Reed the left side of the larynx was slightly flattened, showing an atrophy of the last superior laryngeal muscles. Blood examination showed the red and white corpuscles to be normal in number and the various kinds of leucocytes to be in normal proportion. Hemoglobin normal.

SYMPTOMS, JANUARY 15, 1914.

No change noted since November 8. The mare was transferred to the University Farm, Davis.

SYMPTOMS, FEBRUARY 23, 1914.

No change had been noted since January 15, 1914. The appearance and temperature of the animal while at rest was normal. On exercise she showed the abnormal respiratory symptoms already described. After driving rapidly for one-third of a mile the animal was allowed to stand and in four minutes all abnormal respiratory symptoms had disappeared. Palpation of the larynx revealed atrophy of the superior laryngeal muscles on both sides and a tentative diagnosis of *diplegia laryngis* was agreed upon.

SYMPTOMS, FEBRUARY 24, 1914.

The mare was operated on in a standing position after the manner of Williams and Frost. On opening the larynx the muscles controlling the left arytenoid cartilage were seen to be completely paralyzed and those of the right to be partly paralyzed, verifying the diagnosis on the previous day. The operation was successfully completed although the cricoid cartilage became cracked.

SYMPTOMS, APRIL 18, 1914.

The animal appears to have completely recovered. No abnormal respiratory sounds or symptoms appear even during violent or prolonged exercise. She was returned to the owner at Benicia.

SYMPTOMS, JULY 8, 1914.

Witness No. 138 reports that for some time after her return from Davis the mare was perfectly sound, but lately she has been showing a return of her old symptoms. On examination by Dr. Haring he noticed that she held her head slightly extended as if her throat were sore. On palpation of the larynx he noted that it was hard and stiff, and when pressure of the fingers was made it felt like a mass of solid bone instead of the normally elastic cartilaginous box. In his opinion a chondroma was developing.

SYMPTOMS, JULY 15, 1914.

Mare was inspected by Drs. Haring, Roadhouse, and Wood, accompanied by Drs. Moore, Gardner, and Ernst. No change was noted since July 8.

The photograph reproduced as Plate XXXIX, *C*, was taken July 15, 1914, at the ranch of witness No. 32, Benicia, Cal. From right to left, V. A. Moore, Ithaca, N. Y.; H. C. Gardner, Anaconda, Mont.; John Ernst, Salt Lake City, Utah; (case 4, mare); F. J. Wood, Berkeley; C. L. Roadhouse, Berkeley.

CASE 5.

Owner: Witness No. 23, Benicia.

Location: Ranch of witness No 132, rented by witness No. 138.

Description: Black mare; aged; weight about 900 pounds; white stripe below right eye; white left hind foot. Poor teeth, thin condition.

History: Reported to be a daughter of case 4, having been for many years on the ranch of witness No. 32 and used with case 1 for a driving team and later when symptoms of unsoundness developed they were used mostly for light farm work. Symptoms of unsoundness in wind have been present for several years and have gradually been growing worse.

SYMPTOMS, NOVEMBER 7, 1913.

Same history as case 4.

SYMPTOMS, NOVEMBER 8, 1913.

Animal arrived in Berkeley in company with case 4. The description given for case 4 will apply in most particulars to this animal. She was somewhat thinner and weaker than No. 4, but the respiratory difficulty was not quite so pronounced.

DECEMBER 19, 1913.

Taken to the University farm, Davis, with case 4.

SYMPTOMS, FEBRUARY 23, 1914.

Similar symptoms as those described on this date for case 4. Palpation of the larynx revealed atrophy of the superior laryngeal muscles on the left side of the larynx and a tentative diagnosis of hemiplegia laryngis was agreed upon.

SYMPTOMS, FEBRUARY 24, 1914.

The animal was secured in a standing position and a local anæsthetic administered. The larynx was opened by making an incision through the skin and cryco-thyrodean ligament on the median line and parallel to the long dimension of the larynx. An inspection of the interior of the larynx through this opening showed that the left arytenoid cartilage remained motionless while the right one moved in a normal manner in accordance with the animal's respirations. This verified the tentative diagnosis of the day before of *hemiplegia laryngis*. It was decided to kill the animal. Following are the autopsy notes furnished by Dr. Roadhouse:

DATA SHOWN BY POST-MORTEM OF CASE 5.

Lungs: The middle lobe of the left lung was adhered to pleura over an area of about 1 by 3 inches. The periphery of the principal lobe was thin and unfunctionating, this area being about 2 by 5 inches.

The right lung adhered to the right wall over an area about 1½ inches in diameter.

Liver: The liver was normal in size. Its anterior border adhered to the diaphragm. Two concentric hepatic calculi, calcareous nodules (parasitic nodules) were found in the periphery of the liver.

Colon: The large colon was adhered to the liver. Measurements were taken of the heart and sent to Dr. K. F. Meyer. The larynx was removed and sent to him. All organs and tissues, except those above mentioned, were normal in appearance.

RESULTS OF EXAMINATION OF LARYNX OF CASE 5 BY DR. K. F. MEYER.

On February 26, 1914, examination was made of a specimen of the larynx of case 5, which had been fixed in formalin. Notes thereon are as follows:

The larynx has been opened in its upper part; also wounds in first cartilage ring of the trachea and in the left pouch are present. On reconstruction the larynx is asymmetrical, the left side of the vocal cord is closer to the median line than the right. The muscles are apparently slightly flattened on the left side, but no differences in color are noticed. The left recurrent, being rather long, is close to the insertion in the muscles; flat and thin compared with the right nerve. The difference exceeds the physiological limit, but no change in color is apparent.

Diagnosis.—Atrophy of the left recurrent nerve, and arytenoid muscles of the larynx.

The histological examination showed a general reduction of nerve bundles at the cost of connective tissue growth, which was also seen in the right recurrent.

According to the microscopical examination, the inflammatory process of the recurrent nerves, which is responsible for the muscular atrophy, was bilateral and would have finally led to a diplegia laryngis.

CASE 6.

Owner: Witness No. 4.

Location: Ranch of owner.

Description: Dark bay gelding; aged; gray white forehead and white right hind foot.

SYMPTOMS, NOVEMBER 4, 1913.

Observed by Haring and La Grange while in road; horse pulling up grade showing distressed breathing.

SYMPTOMS, MAY 15, 1914.

Examined by Wood and Adams. They detected atrophy of muscles on left side of larynx. No abnormal respiratory sounds noted while at rest, but roughened breathing could be produced by compressing the larynx. On account of objections by the owner, there was no opportunity to exercise the animal.

CASE 7.

Owner: Witness No. 4.

Location: Ranch of owner.

Description: Sorrel gelding, aged 10 years Three white feet and blaze on face.

SYMPTOMS, NOVEMBER 14, 1913.

Seen by Haring and La Grange. Owner claimed the animal was "smeltered," but objected to an examination.

SYMPTOMS, MAY 15, 1914.

Examined by Wood and Adams. Slight atrophy of left superior laryngeal muscles. No respiratory trouble was noted, but on account of the owner's objections the animal could not be exercised.

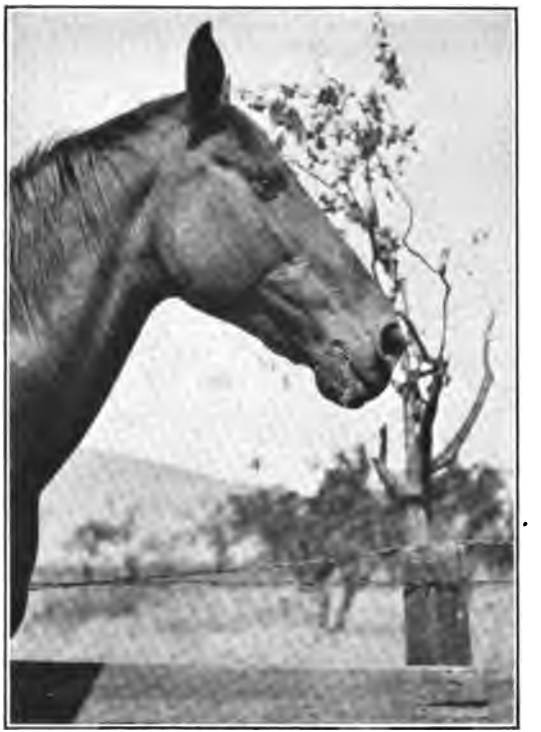
CASE 8.[a]

Owner: Witness No. 13.

Location: Ranch of owner.

[a] See Plate XL, *A* and *B*.

A. "CASE 8," NOSTRILS DURING EXPIRATION AFTER ANIMAL HAD TROTTED A FEW RODS.



B. "CASE 8," NOSTRILS DURING INSPIRATION.

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Description: Black mare; age, 14 years; weight, about 1,400 pounds. Reported by owner to have been of unsound wind for a number of years. Large hernia on left side.

EXAMINATIONS MADE.

October 31, 1913, examined by La Grange and noted to be of unsound wind.

February 7, 1914, examined by Adams and condition noted.

March 7, 1914, examined and observed to be in same condition as at previous inspection.

May 1, 1914, mare had foaled recently and had developed a large rupture on left side.

May 15, 1914, examined by Wood and Adams; condition unchanged.

July 8, 1914, examined by Haring. Owner says unsoundness in wind has not changed for years. The symptoms were as follows:

Atrophy of both superior laryngeal muscles, but especially marked on the left side. Respirations and lung tones normal while animal is at rest. Compression of larynx produces fluttering sound during inspiration. On trotting slowly for 100 yards, typical symptoms of roaring developed, including dilation of and extremely active movements of the nostrils, strident sounds during inspiration, and labored costal abdominal breathing.

July 15, 1914, examined by Moore, Gardner, Ernst, and Roadhouse, and pronounced a typical roarer.

CASE 9.[a]

Owner: Witness No. 12.

Location: Ranch of owner.

Description: Bay gelding; age, 11 years; two white feet behind. Owner says animal has been unsound in wind for past six years.

EXAMINATIONS MADE.

October 31, 1913, examined by La Grange and unsoundness noted.

November 22, 1913, examined by La Grange. No change in condition.

February 7, 1914, examined by Adams. No change in condition.

March 3, 1914, examined by Adams. No change.

May 15, 1914, examined by Wood and Adams. No change.

July 8, 1914, examined by Haring. Symptoms since last fall have remained constantly as follows:

General appearance healthy, but rather thin. Breathing normal when at rest; inspiration roughened when first trotted; later very labored inspiration and strident respiratory noise typical of roaring which occurs only during inspiration. Nostrils are very active, dilating widely on inspiration and closing to normal on expiration. After prolonged severe exercise the nostrils remain widely dilated and trumpet-shaped during both expiration and inspiration and face becomes wrinkled from the efforts of respiration. During inspiration abdominal muscles contract vigorously, intercostal spaces sink in, and ribs become prominent. Palpation of larynx shows atrophy of superior laryngeal muscles on both sides of larynx.

July 15, 1914, case was seen by Drs. Haring, Roadhouse, and Wood in company with Drs. V. A. Moore, H. C. Gardner, and John Ernst, and pronounced to be a typical case of roaring of the diplegia laryngis type.

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[a] See Plate XLI, *A*.

CASE 10.[a]

Owner: Witness No. 12.

Location: Ranch of owner.

Description: Bay gelding; star and stripe on forehead; aged; lower lip pendulous.

EXAMINATIONS MADE.

October 31, 1913, examined by La Grange and unsoundness noted. Thin and in poor condition.

November 22, 1913, examined by La Grange. No change.

February 7, 1914, examined by Adams. No change in condition.

March 3, 1914, examined by Adams. No change in condition.

May 15, 1914, examined by Wood and Adams. No change.

July 8, 1914, examined by Haring. No change.

July 15, 1914, examined by Haring, Roadhouse, and Wood, accompanied by Moore, Gardner, and Ernst. The symptoms were similar to those described for case 9, except that in this animal they are more pronounced. Case 9 outwinded this mare, although No. 9 was drawing a buggy and No. 10 was led behind. This animal showed atrophy of superior laryngeal muscles on both sides.

CASE 11.

Owner: Witnesses Nos. 1 and 1A.

Location: Dairy of owner.

Description: Buckskin mare; black points; white feet; blazed face; weight, 1,300 pounds; age, 8 years.

EXAMINATIONS MADE.

November 10, 1913, examined by Haring. Owner reported case to be of long standing. Was a roarer when he bought her. When worked she showed typical symptoms of roaring. Vibrations can be felt over larynx. Atrophy of left superior laryngeal muscles.

February 7, 1914, examined by Adams. No change.

March 3, 1914, examined by Adams. No change.

April 11, 1914, examined by Dr. Hayes. No change.

CASE 12.

Owner: Witness No. 135.

Location: Benicia, at owner's place.

Description: Bay gelding; stripe on forehead and white hind pasterns. Age, 13 years.

EXAMINATIONS MADE.

November 22, 1913, examined by La Grange, and unsoundness noted.

March 7, 1914, examined by Adams. No change.

April 21, 1914, examined by Hayes and Wood. Marked respiratory sound on inspiration. Pressure on larynx increases sound of breathing. Horse is so thick about the larynx it is impossible to palpate the superior laryngeal muscles. Animal gives characteristic sounds of roaring.

PROBABLE CAUSE OF LARYNGEAL PARALYSIS IN TWELVE CASES MENTIONED.

The symptoms manifested in the above 12 cases are typical of the usual type of roaring due to hemiplegia or diplegia laryngis.

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[a] See Plate XLI, *B*.

A. "CASE 9" AFTER TROTTING A FEW RODS. NOTE DILATED NOSTRILS AND WRINKLED MUZZLE.

B. "CASE 10," AFTER TROTTING A FEW RODS. NOTE DILATED NOSTRILS.

The detection of muscular atrophy of the larynx in 10 of the cases clinched these diagnoses. Five cases showed atrophy of the superior laryngeal muscles on both sides. In cases 4 and 5 the effects of the paralysis in producing the partial closure of the glottis were seen through an incision into the larynx. This proved the correctness of the diagnosis beyond all controversy. Dr. James Law in his textbook of veterinary medicine has given a clear description of this appearance, which I quote as follows:

The modus operandi of this paralysis and wasting in the production of roaring is beautifully seen when the upper part of the windpipe is laid open so as to expose the interior of the larynx in laryngectomy. The triangular opening of the glottis is seen fairly dilated while the muscles are relaxed in the act of expiration. As soon, however, as inspiration commences the left arytenoid cartilage slides completely into the passage, its lower border projecting so much to the right that it forms a prominent crest extending beyond the median line and in some cases closely approaching the right wall of the larynx, the superior elastic and free border of the same cartilage meanwhile gets drawn inward by the suction power of the air so as to block up the passage still more. The closure of the glottis being thus seen to be largely controlled by the current of inspired air, it becomes evident that any increase in the force of the current will aggravate it and a decrease will lessen the extent of the closing and alleviate the distress of breathing. This fact explains why roaring should not be heard in quiet breathing and why it should increase in force and in pitch as the respiration becomes more and more hurried. It further accounts for the noise being heard only during the act of inspiration, the outer rush of the air in the expiratory act being of itself sufficient to carry this valvular cartilage out of the passage and secure a free and unimpeded current.

Roaring in horses due to laryngeal paralysis is described in nearly all books treating of diseases of the horse. I would refer particularly to the following:

Special report on diseases of the horse: Dept. of Agr., 1907, pp. 117, 210, and 223.

Veterinary pathology of Friedberger and Frohner, translated by M. H. Hayes, vol. 2, pp. 686–691.

Pathology and therapeutics of the disease of animals by Hutyra and Marek, authorized American edition of 1913, pp. 729–736.

Textbook of veterinary medicine, by James Law (second edition), vol. 1, pp. 146–161.

It is believed that there are a number of conditions that may bring on paralysis of the larynx in horses, and authorities differ as to what is the most frequent cause. Friedberger and Frohner attribute it chiefly to heredity. Hutyra and Marek say it is usually due to the after effects of infectious diseases. The fact that 50 per cent of the affected horses showed atrophy of the superior laryngeal muscles on both sides of the larynx eliminates the probability of inheritance, after effects of infectious diseases, pressure of enlarged bronchial glands on the left recurrent laryngeal nerve as it rounds the aortic arch, and other pathological conditions that usually affect only the left recurrent laryngeal nerve.

LITERATURE ON THE PULMONARY SYMPTOMS OF PLUMBISM IN HORSES.

Most writers mention chronic lead poisoning as one of the causes of roaring. The following most important references to observations concerning the relation of chronic lead poisoning to roaring in horses include the literature on this point so far as we have been able to find it:

Schmidt, Prussian Report, 1879, reports:

In the neighborhood of lead smelters, horses frequently become affected by lead, with symptoms of difficulties in breathing only. Disturbances of nutrition and other specific symptoms were entirely absent.

Mosslemann and Hebrant, Belgian Annals, 1899, report:

Eight horses on a farm which was situated one-half kilometer from lead works became affected with lead poisoning. A 3-months-old foal showed symptoms of foal evil. Two others, stiffness of the back and limbs. An old mare became affected with hemiplegia laryngis; was cured with treatment of potassium iodide. The same horse showed, later, during feeding, acute attacks of suffocation, with roaring cough, which finally ended fatally. Two other mares also showed acute roaring and dyspnea. The liver of the succumbed horses contained large amounts of lead.

Thomassen (Monatschriften für Psychologie and Neurologie, 1903, p. 423) has shown that the recurrent nerve showed pronounced degeneration in cases of lead poisoning of the horse. In several observations the entire nerve vagus was degenerated. He could experimentally reproduce the conditions by feeding horses with lead.

H. R. Thomassen (Monatshefte für praktische Tierheilkunde, vol. 13, p. 193, and vol. 14, p. 289), 1904, reports cases of hemiplegia laryngis due to lead poisoning.

H. R. Trumbower (Diseases of the horse, U. S. Department of Agriculture, 1907) says:

Lead poisoning may affect the lungs principally. In whatever system of the organs the lead is deposited mostly there we will have the symptoms of nervous debility most manifest. In it the lungs are affected and breathing becomes difficult and the animal gets out of breath quickly when he is compelled to run. Roaring also is frequently a symptom of lead poisoning.

Hutyra and Marek (Pathology of domesticated animals, vol. 2, English translation, 3d ed.), referring to hemiplegia laryngia, note lead poisoning from smelter as a frequent cause of this condition. Aspiration pneumonia and resulting gangrene are mentioned as resulting from laryngial paralysis due to chronic lead poisoning.

Finlay Dun (Veterinary medicines), quoting from Shenton, states that fits and partial paralysis came on at intervals, and when the animals got down they often struggled, for a long time ineffectually, to get up again. The breathing up to this period was tranquil, but now became so difficult and labored that the patients appeared in danger of suffocation. The pulse was in no case above 60 or 70, and

that he ascribed the difficulty of respiration to a paralyzed state of the respiratory apparatus. In the same paragraph he states that Mosselmann and Hebrant consider that the effects of lead poisoning in horses are especially manifested upon the vagus nerve, inducing roaring and dyspnea.

James Law (Veterinary medicines, vol. 1) states that paralysis of chronic lead poisoning will cause roaring.

Naunyn (Vergiftungen durch Schwer-metale und ihre Salze: Ziemssen's Pathologie und Therapie, vol. 15, p. 273) says that the paralysis of the respiratory muscles through lead poisoning is rare, but that it belongs to this great group is evident from the paralysis of these muscles in animals poisoned by lead. The horses in the lead mills frequently suffer complete paralysis of the vocal cords, which makes tracheotomy necessary.

Teleky (Zf. f. Neurologie, vol. 37, 1909) says that only those nerves become affected or degenerate most distinctly that supply the muscles exposed to the severest action. The muscles always atrophy. In most of the cases a certain distinct area of peripheral muscles is affected.

H. A. Vermeulen (Das Kehlkopfeifen beim Pferde, 1914, reviewed in Jour. Comp. Path. and Therapeutics, vol. 27, pt. 2, June, 1914, p. 173) puts forward what appear to be entirely original views regarding the etiology of roaring in the horse. He does not regard the disease as one localized in the larynx, but considers it to be one of widespread disease affecting the motor nerves and their centers. The condition is viewed as one of poisoning, the poison being some traces of mineral or vegetable origin, but in most cases a bacterial toxin or antitoxin, the last of these having its origin in disturbance of function of the thyroid gland.

COMMENTS ON THE PROPORTION AND DISTRIBUTION OF CASES.

It should be noted that the 12 cases of roaring above described are distributed among 8 owners. The total number of horses in the more exposed portions of the smoke zone is 140, making the proportion of roarers about 8.5 per cent of all the horses in this area. It is probable, however, that the true proportion is somewhat larger, as we have not positively diagnosed 11 suspected cases, 5 of which, on account of the objections of the owners or for other reasons, we were not able to study carefully enough to establish a positive diagnosis. These and other cases of pulmonary unsoundness are listed later in the section on live-stock survey.

If we assume that 8.5 per cent of the 140 horses in the area most exposed are roarers, it must be admitted that even such a percentage is larger than is usually encountered among horses. In order to substantiate this statement, we recommended to the Selby Smelter

Commission, in a report on June 22, 1914, that a live-stock survey be made of several near-by sections of identical or similar telluric and botanical conditions, with a view to determining the proportion of roarers. They have not seen fit to have this done (see letter from R. A. Gould, July 3, 1914), but, judging from our knowledge of live-stock conditions in several other sections of California which are agriculturally similar, we (Haring and Meyer) are justified in asserting that 8.5 per cent is an unusually large proportion of roarers. Under any circumstances this proportion would cause us to suspect some one cause for the trouble.

Of the numerous agencies that may be the cause of roaring in horses, the only one that we suspected in these cases was chronic lead poisoning. Reasons for this suspicion will be mentioned later in the discussion of the data collected in the general survey of all the live stock between Vallejo and Benicia.

The following table summarizes the distribution of horses in the smoke zone:

Distribution of horses and of cases in the smoke zone.

Witness No.	Total number of horses owned.	Cases of hemiplegia laryngis or pneumonia positively diagnosed.	Suspected cases of hemiplegia laryngis.	Cases claimed by owners, but no evidence found for such claim.
140 [a]	11		A and B	
37	47			
16	32			
4 [a]	9	Nos. 6 and 7	C	
17 [a]	5			D.
21	9			
141	20			
75 [a]	2			
13 [a]	10	No. 8		
12 [a]	21	Nos. 9 and 10	E and F	G.
5 [a]	5		H	
1 [a]	15	No. 11		K.
27	12			
18 [a]	6			
142 [a]	1		L	
143	3			
25 [a]	9		M	
144	15			
145	1			
29	3			
48 [a]	3			
24	12			
135 [a]	3	No. 12		
8 [a]	5			
28 [a]	7		N	
146	14			
23 [a]	3	Nos. 4 and 5		
11	[b] 18	Nos 1 and 2	O and P	Q.
6	[b] 7	No. 3		R, S, T, and U.
Total	308	12	11	8

[a] One of the horse owners who control the land most directly exposed to smoke. The total number of horses owned by these men is 140, about 8.5 per cent of which are roarers, while the percentage of proven roarers in the 308 horses in the entire area investigated is 3.9 per cent.

[b] The fact that witness No. 6 keeps buying, selling, and transferring old or unsound horses renders it impossible to draw any conclusions from the condition of his stock. The frequent transfer of horses between his land and the ranches rented by witness No. 11 renders it difficult to authenticate the history and methods of pasturing animals belonging to witness No. 11.

ANATOMICAL LESIONS FOUND IN CADAVERS OF HORSES THAT DIED IN SELBY SMOKE ZONE.

On account of the fact that we were rather unfortunate in atopsying (with one exception) only cadavers that had lain exposed to decomposition for more than 48 hours, the support the post mortem findings can give the epidemiological and clinical observations is meager.

In two cases (cases 1 and 3) out of three the diagnosis of a gangrenous pneumonia due to aspiration of food material was fully established. Such processes in the lung tissue lead always to septicemia, or blood poisoning; in rare cases the foreign body is incapsulated. The animal will then recover very slowly from the disease.

The causes for the aspiration of foreign particles into the lungs are numerous, in most cases mechanical obstructions or paralysis of the pharynx have been recorded. Swallowing the wrong way, owing to the paralysis of the pneumogastric nerve has also been seen, we are accustomed to speak of so-called "Vaguspneumonia's." The term would indicate that the pneumonia is the result of a diseased condition of the vagus or pneumogastric nerve. The mucous membrane of the larynx and upper part of the trachea is anaesthetic, the muscles of the larynx are paralyzed, and therefore are unable to expel any foreign body which has been aspirated.

In our cases (1 and 3) a diseased condition of the pneumogastric nerve, in form of an atrophy of the recurrent nerves, was noticed. Unfortunately, in the only case in which the material was fresh, the nerve piece sent with the specimen to the laboratory was very small, and instead of having the entire pneumogastric to examine, a small section of the recurrent nerve had to be used. The macroscopic changes noted were not conclusive, yet they support the microscopic findings—that a reduction in the number of nerve bundles had occurred.

As to the cause of this inflammation and degeneration of the nerve tissue of the pneumogastric nerve and its appendices, the work of Thomassen is of importance. He found, as a sequel to chronic lead poisoning "Vaguspneumonia's," following the paralysis of the pneumogastric nerve.

The anatomical findings on various laryngea (cases 1, 3, and 5) support the clinical diagnosis of hemiphlegia or diplegia laryngis. The organ was invariably more or less asymmetrical and showed atrophied muscles and recurrent nerves.

We have already explained the cause of these conditions and can only repeat that the occurrence of two cases of aspiration pneumonia in one locality in a short interval is exceedingly suspicious for a common cause.

Inasmuch as we believe that in all probability, lead has been the causative agent of the neuroparalysis and the subsequent roaring in the horses of the Selby smoke zone, the cases of aspiration pneumonia are not mere accidents or occurrences by coincidence, but are, in the light of Thomassen's work, the final and fatal results of chronic lead poisoning.

DETAILS OF THE CONDITION OF THE LIVE STOCK BETWEEN VALLEJO AND BENICIA, OCTOBER 28, 1913, TO JULY 18, 1914.

Following is a description of the condition of the live stock on each ranch in the area alleged to have been injured by the Selby smelter fumes. In this list the names of the live-stock owners are, as in previous pages, designated by numbers. The undoubted cases of hemiplegia laryngis are listed with the same case numbers under which they have already been described. The questionable cases of hemiplegia laryngis and the other diseases and unsoundness alleged by the owners to be due to the effect of the smelter smoke have been designated by letters of the alphabet.

Details of the condition of the live stock between Vallejo and Benicia, October 28, 1913, to July 18, 1914.

WITNESS No. 140.

Stock.—6 geldings, 5 mares, 5 cows.

Remarks.—Witness No. 140 has usually objected to an examination of his stock, and it has been impossible to procure complete first-hand information. On October 31, 1913, witness No. 140 told Mr. La Grange that one horse had the chronic form of smelter injury and was almost useless. On November 10, 1913, Dr. Haring called at ranch and examined two cases, A and B. Since then witness has refused any information.

Case A.—Bay gelding about 10 years old, white markings, stripe on face.

November 10, 1913, examined by Dr. Haring. No symptoms of abnormal breathing when run in corral, but owner states that animal shows distress when worked.

Case B.—Sorrel gelding, age 10 to 12 years, weight 1,400 pounds.

November 10, 1913, examined by Dr. Haring. No symptoms of abnormal breathing when at rest. Animal was in a plow team and had just been brought in from farm work. Owner says animal shows distress when worked.

WITNESS No. 37.

Stock.—47 horses.

Remarks.—Many of these horses are used at the tannery in Benicia at certain times. No trouble reported.

WITNESS No. 16.

Stock.—32 horses, 2 cows, 4 heifers.

Remarks.—No trouble. Owner claimed to have suffered loss in past, but not recently. He said he had to stop sheep business on account of losses supposed to be due to smelter.

WITNESS No. 4.

Stock.—6 geldings, 3 mares, 14 cows, 2 bulls.

Remarks.—Two geldings reported as "smeltered." These have been described. (See cases 6 and 7.) Objections by the owner interfered with thorough examination of stock. In addition to cases 6 and 7 the following doubtful case C was observed:

Case C.—Bay mare. Aged. White star on forehead.

Weight about 1,300 pounds. Examined May 15 by Mr. Adams and Dr. Wood.

Pronounced roaring sound on inspiration and grunting on expiration.

Trouble probably due to previous cases of pneumonia.

WITNESS No. 17.

Stock.—5 horses, 1 cow, 1 calf.

Case D.—Gray mare, 15 years old, said by owner to have been affected for 10 years. Found dead January 1, 1914. Was in poor condition before death. No autopsy performed.

No other animals reported "smeltered" at present.

WITNESS No. 21.

Stock.—9 horses, 5 cows.

Remarks.—No trouble exists at this time. Claims losses in the past.

WITNESS No. 141.

Stock.—50 cattle, 20 horses, 200 sheep.

Remarks.—No trouble reported.

WITNESS No. 66.

Stock.—4 ewes, 1 buck, 1 gelding, 1 mare, 2 cows, 2 calves.

Remarks.—Claims losses in the past in horses, cattle, and sheep. No trouble at present. Examined November 22, February 7, March 7, April 11, and May 1.

WITNESS No. 13.

Stock.—5 mares, 5 geldings, 2 cows.

Remarks.—No losses recently. The long standing case of roaring in a black mare has been described as case 8.

WITNESS No. 12.

Stock.—21 horses, 7 cows, 5 heifers.

Remarks.—No losses recently. Two horses on this place are claimed to show effects of past injury. These have been described. (See cases 9 and 10.) In addition, the following doubtful cases E, F, and G, are reported:

Case E.—Large, black gelding. Age, 8 years. White star on forehead; wire cut on right front fetlock.

Said to have been affected for the last eight years. This animal appeared normal while at rest. Condition good.

Case F.—Bay filly, 4 years old, white hind feet; used as saddle horse.

Atrophy of left laryngeal muscles noted. She had not been reported as "smeltered." The owner later stated that there seemed to be nothing the matter with the filly. Respirations appeared entirely normal at rest.

Case G.—Bay mare of witness No. 78, 8 years old. Claimed to be slightly affected.

These animals were reported on by Mr. La Grange on October 31, 1913, and November 22; April 21 by Dr. Hayes, Mr. Adams, and Dr. Wood; on May 15 by Mr. Adams and Dr. Wood; on July 8, 1914, by Dr. Haring; and on July 15, 1914, by Dr. Haring and others.

Witness No. 5.

Stock.—5 horses, 5 cows, 3 heifers.

Remarks.—The owner lives on a ranch owned by Selby Smelter & Lead Co. No trouble claimed of late years, but suspects that injurious fumes occasionally come across from the smelter. In the past the man claimed severe losses. The smelter company bought his ranch and permits him to remain there rent free.

Case H.—Roan horse on place four years, suspected by witness No. 5 of being slightly injured by fumes during the past year. Witness believes that injury from fumes occurs chiefly at night and if the horses are kept in at night no injury will occur.

Witness No. 1.

Stock.—250 cattle, 15 horses.

Remarks.—Two heifers, one mare, and one gelding were said to be "smeltered." The mare has already been described as case 11.

Case I.—Yearling heifer, very poor condition.

Was reported by the owner on October 31 as sick. This animal was killed on November 10 and an autopsy performed by Dr. Haring. Lesions of tuberculosis were shown in the lungs. There was no evidence of any other trouble.

Case J.—Black heifer reported October 31. In very poor condition. Was destroyed November 10 and an autopsy performed by Dr. Haring. Lesions of generalized tuberculosis shown.

Case K.—Dark brown horse. Weight about 1,500 pounds. Age, 9 years. This horse was believed by the foreman of the ranch to be "smeltered." The foreman stated that for a couple of weeks before our visit the horse had been off feed sometimes and had coughed and had some discharge from the nostrils. Respirations, pulse, and temperature were all regular, and there was no evidence of discharge from nostrils at this time, but auscultation of the trachea gave a respiratory sound indicative of bronchitis. No other symptoms were present and it is thought that the horse might have had bronchitis. (Dr. Hayes's report of Apr. 17.) May 15, was examined by Mr. Adams and Dr. Wood and was apparently a good recovery.

Witness No. 27.

Stock.—3 mares, 9 geldings, 2 cows.

Remarks.—No trouble reported.

Witness No. 18A.

Stock.—2 geldings, 2 fillies, 2 colts, 120 sheep.

Remarks.—Claims sheep used to grow thin and die from unknown cause. No trouble at present. Examined October 21, February 2, and May 1. No sheep on place May 1, 1914.

Witness No. 142.

Stock.—1 gelding.

Case L.—Solid gray horse. Weight about 1,000 pounds. Purchased four years ago. The owner stated that the horse had been affected for over a year, much worse in winter when the roads were heavy and the horse was used for buggy purposes. The horse was found on pasture in splendid physical condition. He was required to do very little work, as the roads were good and the owner stated that the symptoms were not very evident now. Pulse and respiration were normal. Palpation of the larynx showed a barely appreciable atrophy of the muscles on the left and superior parts of the larynx. July 15, seen by Dr. Haring and others. No symptoms.

Witness No. 143.

Stock.—3 horses, 4 cows.

Remarks.—No trouble reported.

WITNESS No. 144.

Stock.—90 cattle, 15 horses.
Remarks.—No trouble reported.

WITNESS No. 145.

Stock.—3 cows, 1 gelding.
Remarks.—No trouble reported.

WITNESS No. 29.

Stock.—3 mares, 3 sheep.
Remarks.—No trouble exists at this time.

WITNESS No. 48.

Stock.—3 horses, 1 cow.
Remarks.—No trouble reported.

WITNESS No. 24.

Stock.—12 horses, 35 cows.
Remarks.—No trouble reported.

WITNESS No. 135A.

Stock.—2 mares, 1 gelding.
Remarks.—The gelding is a roarer and has been described as case 12.

WITNESS No. 8.

Stock.—20 cows, 3 horses, 2 colts.
Remarks.—No trouble.

WITNESS No. 25.

Stock.—9 horses, 1 cow.
Case M.—One mare said to be affected by "smeltering." Bay mare, weight about 1,350 pounds, 9 years old. This animal was purchased from the Dos Reis place about 4 years ago, and was known to have shown symptoms of "smeltering" at the time of purchase.

WITNESS No. 28.

Stock.—1 horse, 6 mares, 5 cows.
Case N.—Aged bay gelding. Affected for several years. Apparently normal while standing in barn. Abnormal inspiratory sounds when exercised. Examination showed atrophy of left superior laryngeal muscles. Condition fair. Was reported on by Mr. La Grange on October 31, 1913; by Mr. Adams on February 14, and May 1; and on May 16 by Mr. Adams and Dr. Wood.

WITNESS No. 146.

Stock.—14 horses.
Remarks.—No trouble.

WITNESS No. 147.

Stock.—400 hogs.
Remarks.—No trouble reported. In November, 1913, a few hogs were sick, but recovered. Mr. La Grange thought the cause was dietary, possibly from drinking salt water.

WITNESS No. 23.

Stock.—3 horses.
Remarks.—Two affected with hemiplegia laryngia, and were taken to Berkeley on November 8, 1913. These have been described as cases 4 and 5.

Witness No. 11.

Stock.—18 horses, 8 cows, 700 sheep.

Remarks.—Two alleged cases of smelter injury belonging to witness No. 11 have already been described as cases 1 and 2.

Case O.—One horse died about October 24. Said to belong to witness No. 6, but pastured on ranch of witness No. 11. Cause of death unknown, as carcass was badly decomposed on October 28 when seen by Drs. Haring, Meyer, and Massero.

Case N.—Post mortem report on the horse of witness No. 6, pastured by witness No. 11, October 28, 1913:

Medium nourished horse; mare; cadaver bloated; from anus and mouth oozing of bloody, frothy fluid. In shoulder and hip region, large abrasions without hemorrhages. Subcutaneous tissue infiltrated with serous hemorrhagic fluid; gas bubbles.

Some fluid of reddish color in abdomen. Intestines tremendously distended by gas. Serosa diffusely stained, blackened, submucous gas bubbles. Liver, kidneys, and spleen in a state of advanced decomposition.

In thoracic cavity, reddish fluid with gas; pericard containing bloodstained fluid, imbibition of pericard with blood stain. Blood in heart, tar-like, containing gas bubbles. Lungs very rich in dark blood, but too advancedly decomposed to reveal structure. Larynx and pharynx displaced by fluid and gas masses which proceed along jugular groove.

Bacteriological examination of heart blood revealed putrifying bacteria: B. coli; streptococci.

Epicrisis: No definite diagnosis could be made on account of the advanced decomposition of the cadaver.

The animal probably died on October 24, 1913.

Case P (owner, witness No. 6).—Black mare on place of witness No. 11 in October and was later transferred to the ranch at Elliott Cove. Foaled sometime in March. Seen by Mr. Adams on February 7, 1914, March 7, 1914, and April 11, 17, and 30. Condition fair on ranch at Elliott Cove.

Case Q (owner, witness No. 11).—Light-roan mare. About 9 years old. Weight about 950 pounds. Purchased from a man working at the power company's plant (P. G. & E. Co.) and was said to be "smeltered" when purchased. On May 16 was examined by Mr. Adams and Dr. Wood, and seemed normal even after a short period of exercise.

Witness No. 6.

Stock.—5 horses, 2 colts, 2 cows, hogs.

Remarks.—Witness No. 6 keeps buying, selling, and transferring old or unsound horses, so it is impossible to draw any conclusions from the condition of his stock. In addition to case 3 already described the following were observed:

Case R.—Bay mare. Aged. With colt. Condition very bad, but no roaring when examined on November 10 by Dr. Haring. This mare died January 25, 1914, but no autopsy was performed.

Case S.—Bay mare. Was said by foreman to have shown symptoms of "smeltering," but this animal has never been examined as it was transferred to Vallejo.

Case T.—Brown filly. Two years old. Weight about 900 pounds. This animal was reported to have fallen down and bled from the nose and mouth after having been for some time in the field. No opportunity has been given for examination as the mare was transferred to Crockett.

Case U.—Light-bay mare; star on forehead. Age 15 years or over. There was little history obtainable concerning this animal. It was stated that she had been recently shipped from San Francisco. She had the appearance of having spent several years at hard work on city pavements. Her condition was fair. This animal was found on the hillside on the ranch at Elliott Cove. An abnormal respiratory sound

was distinctly evident during complete rest. Abnormal breathing was somewhat marked. Pulse and respirations were normal and the wings of the nostrils seemed to be dilated. Upon palpation of the larynx, a marked atrophy was present upon the left side of the larynx. This case appeared to be at this stage a typical "roarer," but of course could not be attributed to injury from smelter fumes as she was affected before leaving San Francisco.

On June 11, 1914, at the meeting of the California State Veterinary Medical Association, Dr. Roadhouse and Dr. Hayes performed Williams's roaring operation on this horse. On July 8 the animal was observed by Dr. Haring in a field at the ranch at Elliott Cove and noted to still roar badly.

INTERESTING FEATURES OF THE LIVE-STOCK SURVEY.

Most of the ranchers between Vallejo and Benicia state the belief that the injury from smelter fumes has occurred mainly in horses that were at pasture day and night. The opinion is prevalent that if the horses are kept in barns at night and not allowed in pastures until after sun-up little injury will occur. There is little complaint of injury during recent years. Those who allege that they have suffered loss claim that the symptoms develop in the late summer and fall.

Witnesses Nos. 5, 12, and 13 and others who have lived in Solano County a long time, explain that in the fall, when the pasture forage is dry and shrunken and there has been no rain for several months, the horses constantly at pasture got enough lead to produce injury.

We have already called attention to the fact that the proportion of horses affected with laryngeal paralysis is about 8.5 per cent of all the horses on the exposed ranches. There is reason to believe that in the past the proportion has been even higher than this, and as we have found that no injury has occurred during the past five months the proportion of roarers in time will probably decrease. Unless operated upon, horses affected with hemiplegia laryngis seldom recover. The University of California veterinarians have explained to the owners of the unsound animals that by an operation their animals could be cured. At least the operation is completely successful in about 70 per cent of the cases, and in the 30 per cent of failures the animals are usually no worse off than before the operation. We offered to perform these operations free of charge, but in only two instances (witnesses Nos. 6 and 23) were our offers accepted. However, in case no further injury to the animals occurs from smelter smoke, the proportion of roarers will in time probably decrease, owing to the dying off of the unsound animals, most of which are already advanced in age.

In considering the proportion of horses having laryngeal paralysis, it should be observed that most of the cases were found on farms known to be exposed to smoke from the Selby smelter, whereas on the farms not so directly exposed there were very few cases. An inspection

of the following list in connection with a study of the map will show the correctness of this statement:

Owners known to have cases: Witness No. 4, 2 cases; witness No. 13, 1 case; witness No. 12, 2 cases; witness No. 1, 1 case; witness No. 135A, 1 case; witness No. 23, 2 cases; witness No. 11, 1 case; witness No. 6, 2 cases.

Owners claiming cases, but whose claims could not be verified: Witnesses Nos. 5, 17, 25, 28, 140, and 142.

Owners reporting no cases: Witnesses Nos. 8, 16, 18, 21, 24, 27, 29, 37, 48, 75, 141, 143, 144, 145, and 146.

After noting the location and distribution of the cases of laryngeal paralysis, it is of interest to turn to the following figures, which we are permitted to use through the courtesy of Charles F. Shaw and E. E. Free, the agronomic experts of this commission:

The analysis of the soils conducted under the agronomic survey shows the presence of lead in practically all of the soils of the region and in such quantities as to make it difficult to state that the lead is wholly due to the smelter. It appears that lead in small quantities is a native constituent of the soils of that area. This can not positively be stated without a considerable amount of additional analytical work, which is not deemed by the commission to be necessary. The average amounts of lead found are as follows:

Average quantity of lead found in soil in Selby smoke zone.

Character of area.	Parts of lead per million parts of dry soil.	
	Surface soil.	General soil.
Exposed	15.2	4.8
Not exposed	2.9	4.1

In the matter of lead in the vegetation, we have determined this in a composite of six samples taken from exposed parts of the area, and find 21 parts per one million. This corresponds with about 0.9 gram per 100 pounds of fodder.

These figures are of interest in that they indicate a larger proportion of lead in the surface soil of the exposed areas than in the areas not exposed to smelter fumes. The proportion of lead in the soil is so small that it is of no significance as a source of direct poisoning.

The amount of lead in the vegetation is of more significance, but I know of no data available that would warrant the assertion that the consumption of 0.9 gram of lead per 100 pounds of hay, or about 0.25 gram of lead, per day by a horse would result in symptoms of chronic lead poisoning. In case it seems desirable, feeding experiments on horses could be carried out to determine this point.

SUMMARY OF LIVE-STOCK SURVEY.

The representatives of the pathology and veterinary divisions of the University of California, in visiting the ranches in Solano County that are in the area alleged to have been injured by smoke from the Selby smelter, so far as permitted by the owners, have inspected all the animals and have carefully examined every case of alleged unsoundness. Post-mortem examinations have been made on 4 horses, 2 heifers, and several hogs. No evidence or suspicion whatever of injury from smelter smoke could be detected in the cattle or hogs. In the horses there is evidence that considerable injury has occurred in the past, but we have not been able to discover any evidence of injury since March, 1914.

It would seem that an unusual number of horses in the smoke zone are affected with hemiplegia laryngis, or roaring, and there is reason to suspect that this affection in many cases has been caused by chronic lead poisoning. This suspicion is based on clinical symptoms, however, and not on chemical analyses. Thirty suspected cases of roaring, due to lead poisoning, have been observed, twelve of which have been carefully studied.

The assumption that most of the cases of laryngeal paralysis were caused by lead emanating from the Selby smelter, but that no injury is occurring at present, is justified on the following grounds:

1. The symptoms manifested are typical of the laryngeal paralysis described by various observers as having been caused by lead. Thomassen in particular has performed experiments and described results that are conclusive on this point. Our observation that 50 per cent of the roarers have diplegia instead of hemiplegia laryngis, and the observation of two cases of "Vagus pneumonia," eliminates the possibility of many causes other than lead poisoning.

2. There has been a large proportion of chronic roarers with the occasional development of an acute case in the area exposed to the fumes, in contrast to the absence of roarers in areas not exposed.

3. The usual occurrence of the roarers in the pastures exposed to smelter smoke, and their absence from ranches not so directly exposed, must be considered as evidence favoring the lead-poison theory.

4. The greater proportion of lead found by the chemists of the Selby Smelter Commission in the surface soils of the areas exposed to smelter smoke than in areas not exposed is worthy of consideration in this connection.

5. The almost unanimous assertion by the people living between Benicia and Vallejo that there has been little injury to stock for the past three years, coupled with the fact that we have not been able to find any evidence of injury since March, 1914, justifies us in the conclusion that until additional evidence can be found there is no

reason to believe that at present the smelter smoke is doing any injury to live stock in the Selby smoke zone.

CONCLUSIONS.

It appears probable that in the past considerable damage to horses has occurred in the smoke zone from lead emanating from the Selby smelter.

The effects of this previous injury are still evidenced by a number of long-standing cases of roaring in horses.

The clinical symptoms of roaring in these horses are due to partial paralysis of those muscles of the larynx supplied by the recurrent laryngeal nerves. This paralysis is probably due to the ingestion of lead. In some cases aspiration pneumonia, on account of the paralysis of the pneumogastric nerve, had developed.

The value of the animals affected is reduced 50 to 90 per cent, according to the severity of the paralysis.

In two cases fatal results have been brought on through the inhalation of food particles, which results in gangrenous pneumonia (so-called "Vagus pneumonia").

To date (July 19, 1914), we have not been able to find any evidence of injury since March, 1914.

There is no evidence or suspicion that the smelter smoke has ever injured cattle or hogs.

It is claimed by certain owners that sheep have been injured, but we have been unable to procure any clinical evidence to substantiate such assertions.

Until additional evidence can be found, there is no reason to believe that the Selby smelter smoke is doing any damage to live stock at present (since March, 1914).

BIBLIOGRAPHY ON THE EFFECT OF SULPHUR DIOXIDE ON VEGETATION AND ANIMAL LIFE.

Prepared by the CHEMISTS' CLUB LIBRARY.

ANONYMOUS. Injuries to vegetation by industrial gases. Rauch und Staub, vol. 3, 1913, pp. 109–112. Article states that in all cases of injuries caused by SO_2, the determination of the sulphuric acid content of the injured vegetation, is conclusive evidence. A number of analyses from various localities are given to substantiate this statement. In every case the SO_3 content is proportional to the extent of the injury. Detailed data presented are as follows:

SO_3 content in healthy plants, 0.540 per cent; injured by SO_2: injured leaves, 1.005 per cent; new healthy leaves, 0.640 per cent.

Ash and sulphuric acid content of dry substance of injured needles and leaves.

Tree.	Content of brown parts of—		Content of green parts of—	
	H_2SO_4.	Ash.	H_2SO_4.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Firs	0.929	4.11	1.104	5.73
	.763	5.00	.806	5.08
Oak	.941	4.02	1.023	4.96
Beech	1.028	4.66	1.058	5.40
	.957	5.36	1.063	6.44
Average	.924	4.63	1.011	5.52

Sulphuric acid content of injured leaves on injured tree, 0.769 per cent; of healthy new leaves, 0.516 per cent; of healthy tree, 0.429 per cent.

Sulphuric acid in soils around trees.

Source of soil.	Sulphuric acid content.	
	Oak tree.	Beech tree.
	Per cent.	*Per cent.*
At root	0.162	0.082
Some distance from root	.043	.024
An injured part of forest	.026	.022

Case I.—Source of Smoke, Coke Ovens.

Clover—Injured plants.

Sample No.	Appearance.	SO_2 content, per cent.
I.	Entire leaf surface gray to grayish brown, few spots, and edges	1.542
II.	As above, but less marked	1.198

Clover—Healthy plants.

III.	Normal	0.824
IV.	Normal	.807

Elders—Injured plants.

I.	Leaves, dried up, black	2.330
II.	Normal	1.107

Case II.—Source of Smoke, Rolling Mill.

Pines—Injured needles.

I.	Needles turned completely red, only very few young needles still present	0.449
II.	Practically only young needles, turned entirely red. Some needles with very red tips	.317
III.	Mostly green needles with reddish-brown tips. In some cases entirely red young sprouts	.415

Pines—Healthy needles.

IV.	Apparently healthy, only occasional reddish-brown tips	0.293
V.	Normal	.273
VI.	Normal	.220
VII.	Normal, well-developed	.267

Case III.—Source of Smoke, Coke Ovens.

Firs—Injured needles.

I.	In part entirely brown, in part with brown tips	0.876
II.	Bright green with more or less pronounced brown tips, extending halfway, also some entirely brown	.672
III.	Bright green, only a few needles with brown tips	.413

Firs—Healthy needles.

IV.	Bright green, well-developed, normal	0.286

Case IV.—Source of Smoke, Coke Ovens.

Clover—Injured plants.

I.	Leaves with numerous large and small yellowish-brown to brown spots and edges	1.215
II.	As in I; spots not so numerous	1.236
III.	Only occasional, slightly brownish edges	.726
IV.	Leaves with pronounced yellowish-brown spots and edges	.933
V.	As in IV	1.033
VI.	As in IV, but less marked	.885

Clover—Healthy plants.

VII.	Normal	0.568
VIII.	Healthy	.522

Case V.—Source of Smoke, Coke Ovens.

Potatoes—Injured plants.

Sample No.	Appearance.	SO_2 content, per cent.
I.	Leaves in part entirely dry, in part with pronounced brown spots and edges	2.349
II.	As in I, but less marked	1.361
III.	Leaves in part dry, in part pronounced brown edges and spots	1.603
IV.	Slightly injured	1.200

Potatoes—Healthy plants.

V.	Normal, well-developed	0.647

Beans—Injured plants.

VI.	Leaves small with numerous yellowish-brown spots	1.250

Beans—Healthy plants.

VII.	Leaves healthy green, not very well-developed	0.583

Clover—Injured plants.

VIII.	Leaves with brown spots	1.201

Clover—Healthy plants.

IX.	Healthy, normal	0.601

Wheat—Injured plants.

X.	Leaves with white edges, to some extent yellowish brown facing the coke ovens	2.244
XI.	As in X, but at a greater distance from the coke ovens	

Wheat—Healthy plants.

XII.	Normal, slight white edges	1.747

Oats—Injured plants.

XIII.	Major portion of leaves pronounced yellowish brown	2.012
XIV.	Leaves partly yellowish brown, otherwise well-developed	1.110

Oats—Healthy plants.

XV.	Normal, green	2.552

Case VI.—Source of Smoke, Coke Ovens.

Clover—Injured plants.

I.	Leaves mostly entirely pronounced brown or with brown edges and spots	1.088
II[a].	As in I, but less marked	.964
III[b].	Normal	.734
IV.	Leaves with pronounced brown spots and edges	1.286
V.	As in IV, but less marked	1.191
VI.	As in IV, but less marked	1.133

Clover—Healthy plants.

VII.	Normal	0.830

[a] Taken at a distance of 100 meters from sample I.

[b] Taken at a further distance of 800 meters from sample I and protected from the smoke gases by a forest.

Potatoes—Injured plants.

Sample No.	Appearance.	SO_2 content, per cent.
VIII.	Greatly injured; numerous brown spots and edges	2.357
IX.	As in VIII, but apparently less marked	1.931

Potatoes—Healthy plants.

X.	Healthy, normal	1.039

CASE VII.—SOURCE OF SMOKE, COKE OVENS, ROLLING MILL.

Clover.

I.	Numerous yellowish-brown spots and edges	1.577
II.	As in I	1.546
III.	As in I	1.487
IV.	Injured only to slight extent	.973
V.	Normal, healthy	.478

ANONYMOUS. Recent investigations on the action of acid smoke gases on vegetation. Zeitschr. f. Pflanzenkrankheiten, vol. 16, 1906, pp. 165–181, 343–350. The article presents a comprehensive review of the literature appearing from 1900 to 1906, with special emphasis on Wieler's book and the work of Sorauer.

ANONYMOUS. Smoke injuries. Schweizer. Zeitschr. für Obst- und Weinbau, vol. 13, 1904, pp. 232–233.

ANONYMOUS. The action of sulphurous acid and the residue of cellulose manufacture on plants. Agricultural Institute of the University of Königsberg. Published prior to 1905. (See Stutzer.)

ABBADO, ——. Smoke and injuries to vegetation. Stazioni sperimentali agrarie italiane, vol. 38, 1905, pp. 909–962; vol. 39, 1906, pp. 97–118; vol. 39, 1906, pp. 385–405. Contains a comprehensive review giving the results of the experimental work of others. The work is not confined to sulphurous acid.

ASCHER, ——, and OTHERS. First report of the Königsberg commission for the prevention of smoke. Reprinted in Schriften der Physikalisch-ökonomischen Gesellschaft Königsberg, vol. 48, No. 2, 1908. Abstracted in Gesundheits-Ingenieur, vol. 31, pp. 429–430. Describes a method for determining the SO_2 content of air.

BRIZI, ——. Injuries to vegetation caused by smoke from industrial plants. Stazioni sperimentale agrarie italiane, vol. 36, 1903, pp. 279–384. Abstracted in Zeitschr. für Pflanzenkrankheiten, vol. 14, 1904, pp. 160–163. Treats extensively of the injuries to vegetation caused by smelter fumes; describes the various signs of injury; includes results of laboratory tests to show that field damage can be reproduced in the laboratory by burning sulphur to sulphur dioxide.

COHEN, ——, and RUSTON, ——. Smoke: A study of town air. London, 1912, 88 pp. Contains a chapter on gaseous impurities, including the sulphur acids.

CROWTHER, ——, and RUSTON, ——. The nature, distribution, and effects upon vegetation of atmospheric impurities in and near an industrial town. Jour. Agricultural Sci., vol. 4, No. 1, 1911, pp. 25–55. Abstracted in Botanisch. Zentralbl., vol. 117, 1911, p. 631. The investigations were made in and near Leeds, England, and covered a period of three years. The extent of the injuries was determined by a study of the rain water collected during that period and its action on vegetation. Free acid included both sulphur dioxide and sulphuric acid, but was calculated as the latter. Both potted plants and grasses were subjected to the action of rain water and dilute acid solutions. The presence of free acid is detrimental to vegetation, first, by direct action upon leaves, and, second, by inhibition of the activity of nitrifying and nitrogen absorbing bacteria

of the soil. The continued application of acid rain water tends to decrease the protein content of grasses, etc., and to increase the amount of crude fiber, thus diminishing the nutritive value.

DI STEFANO, ——. Method of ascertaining damage done to cultivated plants by sulphur dioxide. Stazioni sperimentali agrarie italiane, vol. 46, pp. 580–582; Chem. Abs., vol. 8, No. 15, 1914, p. 2739. Author states that in the case of annuals, the whole foliage may be used; with trees only the leaves affected should be. The sample should be protected from the heat and from drying. Five grams of the ground material is treated with distilled H_2O, stirred with a glass rod, covered and let stand 48 hours in a cool place out of the sun's rays, being stirred occasionally. Ten c. c. is decanted into a test tube, 1 c. c. of 2 per cent HI is added, and the mixture is stirred. Then 1 c. c. of $CHCl_3$ is added and thoroughly mixed. If a violet color appears SO_2 is present. If a negative result is obtained, the test should be repeated after the H_2O extract has been allowed to stand another 24 hours.

EATON, ——. On the effect of arsenical and sulphur fumes on vegetation Agricultural Bulletin of the Straits Settlements and Federated Malay States, 1910, vol. 9, pp. 46–51. Abstracted in Exp. Sta. Rec., vol. 22, p. 646. States that in view of the supposed deleterious effect of the fumes from the Chinese furnaces roasting low-grade tin ores, a small furnace was erected in the grounds of the Institute for Medical Research, and actual experiments were conducted with a number of potted rubber plants.

EBAUGH, W. C. Gases versus solids. An investigation of the injurious ingredients of smelter smoke. Jour. Am. Chem. Soc., vol. 29, 1907, pp. 951–970; Chem. Abs., vol. 1, p. 2868. States that the effect of sulphur dioxide was studied by the action of the gas upon sugar beets and alfalfa growing in Utah. The apparatus consisted of a sectional cabinet, 4 by 4 by 4 feet, through the top of which was suspended a fan for mixing the gases, several thermometers, and an inlet tube for SO_2. The tube consisted of a two-way stopcock, one branch of which led to a bottle containing a known amount of iodine. The experimental plants were isolated and surrounded by the cabinet. Definite concentrations of SO_2 were used, and the amount introduced was determined by absorption in iodine. The dilute gas remained in contact with the plants for one hour and was then removed by opening the door and permitting access of fresh air. The process was repeated at definite intervals. When diluted to the amounts that can be present in the air from a smelter, sulphur dioxide must be applied repeatedly to plants to cause material injury. Contrary to Haselhoff and Lindau, damage is rare during clear dry weather, but usually occurs during damp weather. The effect of aqueous solutions of sulphur dioxide and sulphuric acid was also studied, together with the action of the solid particles of smoke on vegetation, and the conclusion is drawn that in the past too little emphasis has been placed on the latter factor.

EICKE, ——. Damage from smoke in the Rhenish-Westphalian industrial district. Rauch und Staub, vol. 3, 1913, pp. 162–167; Chem. Abs., vol. 7, p. 2276. Contains a review of papers of others, but presents no original work.

FARNET, ——. Effects of locomotive fumes on leaves of plants. Rev. Patologia vegetali, vol. 2, 1907, pp. 113–128.

FEIST, ——. Proof of an injury to pines by roasting gases. (SO_2). Archiv. der Pharmazie, vol. 249, 1911, pp. 7–9. Abstracted in Botanisch. Zentralbl., vol. 116, p. 553. The fact of injury was established by the comparative analyses of injured and uninjured pine needles. In the former, both the sulphuric acid and the ash contents were increased, as was true of the soils in which the injured needles were grown.

Results of analyses.

Substance analyzed	Ash.	H_2SO_4.
	Per cent.	*Per cent.*
Healthy pine needles	4.59	1.09
Injured pine needles	6.04	1.69
Soil from district producing healthy needles	.....	.14
Soil from district producing injured needles	.....	.17

FRAZER, PERSIFOR. Causes of injury to vegetation in an urban villa near a large industrial establishment. Trans. Am. Inst. Min. Eng., vol. 38, 1907, pp. 498–519. Includes a bibliography of 46 references. States that injury to vegetation is mainly due to the sulphur oxides in the smoke from industrial plants. In order to verify this statement a series of tests was undertaken, in which the sulphur oxide content of the air around a large plant was determined under all sorts of conditions, and it was established that as a result of the combustion of fuel there was sufficient SO_2 and SO_3 in the atmosphere to have caused all the injuries manifested. Special apparatus was used in the analyses.

GEMUEND, ——. Atmospheric impurities in large cities. Deutsche Vierteljahresschrift f. oeffentliche Gesundheitspflege, 1908, pp. 401–429. General discussion emphasizing effects of dust and soot. The latter contains absorbed sulphur dioxide and sulphuric acid, which have a caustic action on the respiratory organs when inhaled. No experimental data are given.

GERLACH, ——. Beitraege zur Ermittlung des Holzmassenverlustes in folge von Rauchschaeden. (Notes on determining the loss of wood due to injuries by smoke.) Berlin, 1910, 81 pp.

———. Die Ermittlung des Saueregehaltes der Luft in der Umgebung von Rauchquellen und der Nachweis seines Ursprungs. (The determination of the acid content of the atmosphere in the vicinity of sources of smoke and the identification of its origin.) Berlin, 1909, 29 pp. The table of contents is as follows: Preface; 1. Basic principles and methods of my qualitative and quantitative analyses of smoke; 2. Description of, and directions for, improved smoke-analysis apparatus, models 1908 and 1909, German Gebrauchs Muster, Nos. 347784 and 373496; 3. Results obtained up to the present with the analyzer; 4. Conclusion.

———. Observations on, and experience with, characteristic means of showing, or signs of, smoke injuries. Oesterreich. Forst und Jagd Zeit., vol. 25, 1907, pp. 145–148. Abstracted in Botanisch. Zentralbl., vol. 105, 1907, pp. 360–361; Jahresber. der Vereinigung der Vertreter der angewandte Botanik, vol. 6, pp. 75–76. Describes various characteristic phenomena that give evidence of smoke damage, such as the presence of certain insects, the lowering of the power of evaporating water, etc.

———. Besondere Vorkommnisse und Beobachtungen bei Waldbeschädigung durch Rauchgase. (Special occurrence and observations in the case of forest injuries caused by the gases in smoke.) Zeitschr. f. Forst und Jagdw., vol. 40, 1908, pp. 429–437. Discusses injuries caused by sulphur dioxide and sustained by various pines and evergreens, bringing forward new proof of the author's observations, made in 1907, that such injuries are always accompanied by abnormal development of the parasites *pissodes*, *harzyniæ*, and *scabricollis*.

GRAFE, VIKTOR. Injuries to vegetation by waste gases and effluents. Monatshefte f. Landwirtschaft, vol. 2, No. 1, 1909, p. 19.

GRIMALDI, ——. Injuries to vegetation caused by fumes from a copper smelter. Stazioni sperimentale agrarie italiane, vol. 36, 1903, pp. 513–517.

GROHMANN, ——. Erfahrungen und Anschauungen ueber Rauchschaeden im Walde und deren Bekaempfung. (Experience with, and theories of, smoke injuries in forests and their prevention.) Berlin, 1910, 44 pp. Table of contents is as follows:

Introduction.
How do forest injuries by smoke take place?
Caustic injuries.
Resistance of various woods to this type of injury.
Importance of soil conditions.
Various diseases caused by acids in smoke.
Comparison of the two types of injury.
Conditions decreasing or increasing injury.
Of what importance are smoke injuries in forestry?
Preventive principles.
Conclusion.

HALDANE, J. S. The relation of sulphur in lighting gas to air vitiation. Jour. Gas Light, vol. 83, 1903, pp. 564–565. The ill effects resulting from the combustion of illuminating gas containing sulphur compounds are due to the formation of both sulphurous and sulphuric acids, both of which are injurious to health. Gases containing various amounts of sulphur were burned in rooms and the various effects on humans—closeness, acid taste, tendency to headache, sneezing, etc.—noted. With 40 grains of sulphur per 100 cubic feet of gas, a taste of sulphurous acid and slight irritation of the air passages were distinctly noticed at about 13 volumes of carbonic acid per 10,000. With only 9 or 10 grains of sulphur, on the other hand, similar irritation of the air passages was not noticed until the carbonic acid rose to about 35 or 40 volumes; and even at this point no acid taste could be detected—possibly because any sulphurous acid formed had been almost entirely oxidized to sulphuric acid. It was thus evident that the unpleasantness of the air varied in proportion to the amount of sulphuric and sulphurous acid present. With 51 grains of sulphur in the gas and 39 volumes of carbonic acid in the air, distinct fog was observed in the room, although no moisture had condensed on the windows, and the air was only 81 per cent saturated with moisture, as was shown by the readings of dry and wet bulb thermometers (23.5° and 21.5°). The air was extremely unpleasant. The fog was more evident when with the same gas burning and the air 82 per cent saturated with moisture, the carbonic acid had risen to 48 volumes. When the air contained about the same proportions of moisture and carbonic acid, with only the ordinary gas burning, no distinct fog could be seen. In one individual, sneezing was produced on going into room 1 with 35 volumes of carbonic acid in the air, and 36 grams of sulphur in the gas. Two others complained of slight headache after a few minutes.

HASELHOFF, E. Investigations on the action of sulphurous acid on soil. Zeitschr. f. Pflanzenkrankheiten und intern. phytopathalogischer Dienst, vol. 1, No. 3, 1908, pp. 73–91. Abstracted in Botanisch. Zentralbl., vol. 110, 1909, pp. 218–220 The first part of this work describes a continuation of previous investigations. SO_2 was introduced into the soil during the period of vegetation. The arrangement used was as follows: A funnel of such diameter that it fitted snugly into the flower pot was bent below the neck of the funnel and drawn out in such a way that it stuck out of the pot and in this way simplified the introduction of the SO_2. In the lower part of the funnel there was a glass plate, pierced with holes and covered with cotton to prevent the soil falling through. The previous conclusions were confirmed. The second part of the work is devoted to a discussion of the action of sulphurous acid on soil containing copper.

HASELHOFF, E. Memorial volume in commemoration of the 50th anniversary of the agricultural station at Marburg (Germany). Marburg, 1907, 93 pp. Contains Haselhoff's work on the action of sulphurous acid.

———. The action of sulphurous acid, zinc oxide, and zinc sulphate on soil and vegetation. Jahresber. der landwirtschaftlichen Versuchsstation, No. 4, 1903–4. States that the investigations were undertaken to determine the possible injuries to vegetation from the waste gases of a zinc smelter. For this purpose a series of tests was undertaken, in some of which the soil received an addition of lime; in the remainder the soil remained untreated. Sulphurous acid (as SO_2), ZnO, and $ZnSO_4$ were then added. Sulphurous acid in the soil is immediately oxidized to sulphuric acid. The H_2SO_4 content of the soil rose from 0.076 to 0.139 to 0.153 per cent. It may be concluded that a soil would not become barren on account of the action of SO_2 if there be sufficient bases present in the soil to combine with the sulphuric acid formed. Wheat was used for these experiments.

HASELHOFF, E. and GOESSEL, ——. The action of sulphurous acid, zinc oxide, and zinc sulphate on soil and vegetation. Zeitschr. f. Pflanzenkrankheiten, vol. 14, 1904, pp. 193–201. Abstracted in Botanisch. Zentralbl., vol. 96, 1904, p. 619. States that in the investigations restricted to a study of the effect of sulphurous acid, SO_2 was added directly to the soil. The soil was introduced into flower pots with a surface of 300 sq. cm., each pot containing 8.5 kg. of soil. Three pots were used in each series of experiments. In one series 10 grams of $CaCO_3$ was added to the pot. The procedure was as follows: 4 kg. of soil was taken from each of three pots, mixed, and the 12 kg. thus obtained introduced into a wooden box. Through this box there passed five connecting glass tubes, which, within the box, were perforated with many tiny holes, these serving for the distribution of SO_2 through the soil. The soil retained the SO_2 inasmuch as no odor of SO_2 could be detected. For liberating the SO_2 a mixture of three parts calcium sulphite and one part gypsum was decomposed by HCl. The soil was treated with gaseous SO_2 on two different days for three and two hours, respectively, after which all was thoroughly mixed and distributed among the three pots from which it had been taken. The next spring the treatment was repeated for two days of five hours each, after which corn was planted. The conclusions drawn follow: The sulphuric acid content of the soil is increased by the action of sulphurous acid. Vegetation is not injured if the soil contains sufficient bases (lime) to neutralize the acid. The sulphuric acid content of vegetation is proportional to the sulphuric acid content of the soil.

HASELHOFF, E., and LINDAU, G. Die Beschadigung der Vegetation durch Rauch (Injuries to vegetation by smoke). Leipzig, 1903, 412 pp.

HASENBAEUMER, ——, and OTHERS. Determination of injuries to vegetation by smoke gases. Paper read before Medizinische Naturwissenschaftliche Gesellschaft zu Muenster. Abstracted in Rauch und Staub, vol. 3, 1912, pp. 59–60.

HAYWOOD, J. K. Injury to vegetation by smelter fumes. U. S. Bureau of Chem., Dept. of Agriculture, Bull. 89, 1905. States that for the actual experimental work a cabinet 5 by 2 by 4 feet, with glass sides, was built, and this was so arranged that it could be lifted from its base for the introduction of plants. At the front was a door 1 foot square. The cabinet was practically air-tight. Carbon bisulphide was burned for the production of the sulphur dioxide, and the latter was distributed uniformly by means of an electric fan. The plants were fumigated for one hour and then thoroughly aired, receiving three to four successive treatments per day. With both pines and cowpeas positive results were obtained, injury being established with an increase in the sulphur trioxide content. An examination of the vegetation in the vicinity of the smelter at Redding, Cal., gave positive evidence of injuries due to sulphur dioxide. These injuries extended over an area at least 3½ miles north, 9 miles south, 2½ miles east, and five-sixths of a mile west of the smelter.

HAYWOOD, J. K. Injury to vegetation and animal life by smelter wastes. U. S. Bu. of Chem., Dept. of Agri., Bull. 113, 1908. The preliminary report on this work was published in Jour. Am. Chem. Soc., vol. 29, 1907, pp. 998–1009. Bulletin states that the experimental methods are the same as those described in Bulletin 89 of the Bureau of Chemistry. The conclusion is drawn that sulphur dioxide is injurious to the growth and development of trees and foliage. The results of the field experiments on smelter fumes are given in the abstract of the article referred to above.

——— Injury to vegetation and animal life by smelter fumes. Jour. Am. Chem. Soc., vol. 29, 1907, pp. 998–1009. Chem. Abs., vol. 1, p. 2870. Gives a brief review of the results published by the author in Bulletin 89 of the Bureau of Chemistry and discusses the investigation carried out at Ducktown, Tenn. The resistance of trees to the action of sulphur dioxide varied with the species. The injury was determined by means of the sulphur trioxide content. The vegetation around Ducktown was injured for at least 10½ miles north, 8 miles south, 5 to 5½ miles east, and 8½ miles west. The injury was probably more extensive, but could not be established from the chemical analyses. The same conclusions will probably be arrived at in an investigation now (at the time of article) being conducted in the vicinity of the smelter at Anaconda, Mont. This paper is a preliminary report on Bulletin 113 of the Bureau of Chemistry.

——— Injury to vegetation and animal life by smelter wastes. U. S. Bu. of Chem., Bull. 113 (revised), 1911. Chem. Abs., vol. 5, 1911, p. 1055. In addition to recapitulating all previous data, further analytical results on the injuries to trees are given.

——— Smelter smoke. Science, vol. 26, 1907, pp. 476–478. Chem. Abs., vol. 2, 1908, p. 255. The writer refutes some of the statements and conclusions expressed by Ebaugh in the Journal of the American Chemical Society, vol. 29, 1907, pp. 951–970.

HEDGCOCK, G. G. Injury by smelter smoke in southeastern Tennessee. Jour. Wash. Acad. Sci., vol. 4, Feb. 19, 1914, pp. 70–71.

——— Winter killing and smelter injury in the forests of Montana. Torreya, vol. 12, 1912, pp. 25–30. Discusses the physical differences in coniferous trees injured by frost and those injured by sulphur dioxide.

HERBIG, ——. Smoke damage from boiler fires. Zeitschr. angewandte Chem., vol. 22, 1909, p. 1882. Chem. Abs., vol. 4, 1910, p. 244. Gives method of determining SO_2 content of smoke and the atmosphere, as follows:

The air was sucked through a filter by means of a water suction pump so as to remove the soot, and then through a solution of iodine, a flask with iron filings and a gasometer. Three flasks placed behind each other and filled with iodine potassium iodide solution served for absorbing the sulphurous acid. The absorption was complete in spite of the rapid passage of the air (10 to 40 cubic meters per week). The sulphurous acid was determined as $BaSO_4$ after the iodine had been removed by evaporation over a spirit lamp. The flask filled with iron filings was for the purpose of holding back the iodine vapors passing over.

The volume percentage of SO_2 was obtained in the first place titrimetrically by using accurately prepared N/10 iodine solution, and secondly gravimetrically by absorption and oxidation of the SO_2 with sodium hypobromite. E. Rupp (Zeitschr. anal. Chem., 1906, p. 256) uses a solution for oxidizing (formic acid) which is obtained by the gradual addition of 30 grams of bromine to 30 grams of caustic soda dissolved in 900 c. c. water and diluting to a liter.

According to the equation $2NaOH+2Br=NaOBr+H_2O$, 60 grams of bromine is required for 30 grams of caustic soda.

In the volumetric determinations a 10-bulbed tube filled with standardized iodine was attached directly to the gasometer. For the absorption of the vaporized iodine carried along by the stream of gas four Volhard-Fresenius absorption flasks

filled with pure potassium iodide solution were also connected with the ten-bulb tube.

The velocity of the gas current could be only an average one so as not to bring about any loss of iodine, so that in passing through large quantities of smoke the duration of the experiment becomes exceedingly long, and in this way sources of errors may be formed.

For the gravimetric determinations with hypobromite and iodine solutions, two ten-bulb tubes placed behind one another were filled with 75 c. c. of bromine and iodine solution, respectively, diluted to 125 to 130 c. c., and these were connected with a Peligot tube filled with caustic soda solution.

The gravimetric method is the best that can be used. For this purpose 100 to 150 liters should be passed through a suitable absorption arrangement in a not too rapid stream.

KISSKALT, ——. The influence of the inhalation of sulphurous acid on the development of pulmonary tuberculosis. Zeitschr. f. Hygiene, vol. 48, 1904, pp. 269–279, states that the dogs chosen for the experiments were placed in a box 54 cm. square. Sulphurous acid was produced by the combustion of carbon bisulphid and was drawn through the chamber by means of a water pump. The gas was not produced in the experimental chamber itself. Behind the latter was a tube filled with soda lime, after which the air passed through a gasometer. With concentrations of 0.05 to 0.07 part per thousand, it was found that the resistance to pulmonary tuberculosis was diminished appreciably.

KNIGHT, ——, ROSE, —— AND CROCKER, ——. Effect of various gases and vapors on etiolated seedlings of the sweet pea. Paper read before botany section, American Association for the Advancement of Science, Boston, 1910. Science, vol. 31, 1910, pp. 635–636. Includes discussion of effects of sulphurous acid.

KOENIG, ——. Die Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe. (Examination of agriculturally and technically important materials.) Berlin, 1911. Gives methods of determining injuries to vegetation caused by smoke and dust.

KOENIG, ——, AND HASENBAEUMER.——. Influence of sulphurous acid on plants and fishes. Fuehling's Landwirtschaftliche Zeit., vol. 51, pp. 853–857, 893–895, 1902. Abstracted in Biedermann's Zentralbl. f. agrikultur Chem., vol. 32, 1903, p. 535, states that the investigations were undertaken to determine the injury caused by sulphurous acid when occurring in sulphite cellulose wastes. For this purpose, sulphurous acid, both free and in the form of calcium salts, was added to the feed water of both plants and fishes. Injurious action was apparent in both instances.

KOSMANN, ——. Sind Ringofengase der Vegetation schaedlich? (Are the gases from circular furnaces injurious to vegetation?) Verlag der Tonindustriezeit. 112 pp. 1903.

LEHMANN, ——. Recent investigations on the quantitative absorption of several poisonous gases by animals and men by means of the respiratory tract and its branches. Archiv f. Hygiene, 1908, vol. 67, pp. 57–98. In the case of sulphur dioxide, the experiments were made with rabbits and men. The amounts of gas in the air breathed by rabbits varied from 38 to 603 parts per million. The proportion of gas absorbed varied from 35 to 58 per cent, the larger figure being obtained with more dilute gas mixtures. The three experiments upon man were made with concentrations of 14 to 24 parts per million, and showed absorption of from 65 to 79 per cent of the sulphur dioxide that entered the lungs.

LINDAU, G. Recognition and prevention of injuries to vegetation by smoke. Gesundheits Ing., vol. 26, 1903, pp. 78–81; Mitteilungen aus der Praxis der Dampfkessel- und Dampfmaschinenwesen, vol. 26, pp. 793–795, gives short extract from Haselhoff and Lindau on the action of sulphur dioxide.

LINDAU, G. Die Beschädigung der Vegetation durch Rauch. Injuries to vegetation by smoke. Naturwissenschaftliche Wochenschrift, vol. 18, 1903, pp. 421–427. Short review of work of Haselhoff and Lindau.

LIPMAN, ——. Effect of smelter wastes on plant growth. Unpublished paper read before Southern California section of the American Chemical Society, May, 1914.

LOECKERMANN, ——. A new method for the prevention of injury to vegetation by smoke. Fuehling's Landwirtschaftliche Zeit., vol. 60, 1911, pp. 198–210. Deutsche Obstbau Zeit., 1911, pp. 67–69. States that in the past too much emphasis has been placed on the direct action of sulphurous acid and the injuries caused thereby. As a matter of fact, the indirect action—removal of lime from the soil—also plays an important part in the phenomena encountered. The article treats particularly of the work of Wieler, who proposes the addition of lime to the soil as a remedy for the injuries suffered.

MANN, ——. Damage caused by smoke. L'Horticuiture Nouvelle, 1906.

MUELLER, E. Injuries to leaves and fruits of our fruit trees which have been sprayed with properly prepared copper solutions caused by the sulphurous acid smoke of factories, particularly because of heating with sulphur containing lignite and coal. Obstgarten, No. 11, 1903. Abstracted in Zeitschr. f. Pflanzenkrankheiten, vol. 14, 1904, pp. 288–289. States that sulphurous acid forms cupric hydrate on leaves that have been sprayed with copper solutions, and this is oxidized to soluble carbonate and finally sulphate, which has a caustic action on leaves, etc., destroying protoplasm and chlorophyll and thus causing spots, decolorization, desiccation, etc.

NASINI, ——, CUBONI, ——, AND MATTIROLO, ——. Chronic poisoning of fruit trees by factory smoke. Perizia giudiziaria, vol. 4, 1912, 82 pp., Bull. Bu. Agri. Intell. and Plant Diseases, vol. 3, p. 1045.; Chem. Abs., vol. 7, 1913, p. 1893. States that the gases issuing from the factory chimney contained 0.04 to 0.08 per cent SO_2, as more or less air was allowed to enter the furnaces. The leaves became yellow at the edges; a gradual discoloration of the chlorophyll granules occurred; the plasma became yellow; the injured leaves had a high sulphur content.

Relazione di perizia neli a causa sommaria di Garroni contro Societa anonima di lavorazione dei Carboni fossili e loro sotto prodotti. (Account of the suit of Garroni against the Societa anonima di lavorazione on injuries caused by smoke.) Torino, 83 pp. 1911.

NESTLER, ANTON. Urban factories and city air.

Sammlung von gemeinsamen Vortraege herausgegeben von dem Deutschen Verein zur Verbreitung gemeinsamer Kunst in Prague, 1905, Nos. 326–327, pp. 153–175.

NEUMANN, ——. Vegetation in the neighborhood of the Freiburg smelter.

Dritter Bericht des Vereins zum Schutze und zur Pflege der Alpenpflanzen, 1903, pp. 64–69.

OSTERHOUT, ——. On the effect of certain poisonous gases on plants.

University of California Publications. Section on Botany, vol. 3, No. 4, 1908, pp. 339–340.

Abstracted in Exp. Sta. Rec., vol. 20, p. 434. States that experiments were carried out to determine a method of distinguishing the effect of smelter fumes from that of drought and similar natural causes. This was accomplished.

RAMANN, EMIL. Über den Nachweis von Rauchschäden. (Determination of injuries caused by smoke.) Allgemeine Forst und Jagd Zeit., July, 1908, pp. 233–236. Abstracted in Zeitschr. f Pflanzenkrankheiten, vol. 19, 1909, pp. 346–347.

Opposes views of Gerlach (1907). In Gerlach's paper a method for determining the sulphur dioxide content of the atmosphere is given, together with a number

of characteristic signs of injury by smoke. Ramann objects to Gerlach's statement about the presence of insects in smoke-damaged forests. In the case of acute injury insects will shun such trees, but seek trees with chronic injuries. Chemical analyses of the needles will always be the basic method of identification of injuries and all other phenomena will always be subsidiary to this. The paper does not give any analytical data, but merely states that chemical analyses of the leaves and the presence of smoke constituents therein is the only incontrovertible proof of damage produced by smoke. It criticizes Gerlach's paper, which claims that the presence of certain insects and the dropping off of the pine needles are indications of injury by smoke. Ramann claims that such indications will not sustain a suit for damages in court, as these symptoms may be brought about by other conditions.

———. Waldbeschädigung durch Rauch. (Injuries to forests by smoke.) Zeitschr. f. Forst und Jagdw., January, 1908, pp. 32–35. States that injuries to evergreens in the vicinity of a mill were traced to sulphur dioxide from the chimney gases. The physical characteristics and SO_2 content of the needles are given. Pines were not injured, which proves only that the sensitiveness of various trees depends on local conditions.

RIPPERT, ——. Notes on the determination of smoke injuries in the Rhenish-Westphalian industrial district. Glückauf, vol. 48, 1912, p. 1993. Abstracted in Rauch und Staub, vol. 3, 1913, pp. 150–154; Feuerungstechnik, vol. 1, 1913, p. 168. Chemiker Zeit. Repertorium, 1913, p. 611.

States investigations were carried out in the vicinity of coal mines and coke ovens. Inasmuch as sulphur dioxide is the most injurious component of smoke, the study of that factor was emphasized. The experimental arrangement in the examination of the air was somewhat similar to that adopted by both Wieler and Gerlach. Only under exceptional conditions will the sulphur dioxide content of the air in the vicinity of such plants be high enough to cause appreciable injury. Injuries are caused not only by direct action on leaf parts, but also by action on the soil resulting in the removal of plant nutriments. A critical discussion is given of the various methods of establishing injuries by sulphur dioxide. Wislicenus (Zeitschr. angew. Chem., 1901, p. 689) as a result of his investigations comes to the conclusion that the limit of injury lies at an acid content of the air of 1:500000. Wieler (Untersuchungen ueber die Einwirkung schwefliger Saeure auf Pflanzen, p. 357) arrived at the same limits in his investigations. This limit, however, is true of plants most sensitive to smoke, of the coniferous woods, which, according to the investigations of Wislicenus, are injured only if their exposed organs are subjected to an atmosphere which contains 1 part of SO_2 in 500,000 parts of air during the entire period of development. Agricultural plants are much more resistant as Wieler's investigations have shown. The spores of grains, and young sprouts can, therefore, be subjected to an atmosphere with very high acid content without suffering injury. Thus, for example, wheat and rye plants were not injured when exposed to an acid atmosphere of 1 to 50,000. In experiments with beans, which are very resistant, the following results were obtained:

Results of experiments.

Period of experiment.	Ratio of SO_2 to air.		Action on vegetation.
	At beginning.	At end.	
Hours.			
6½	1:256000	.....	Uninjured.
8¾	1:471700	1:165000	Do.
5¼	1:117500	1:138000	Do.
6½	1:82300	1:87500	Do.
10	1:108000	1:130000	Slight injuries.
9	1:27000	.....	Pronounced spots.
9	1:76000	1:96000	Doubtful.
8½	1:218000	1:411000	Uninjured.
9	1:147000	1:227000	Do.
7½	1:116000	1:180000	Do.

Experiments of Wieler with forest trees show that pines and beeches are especially sensitive whereas oaks possess a higher resistance. An acid content of 1:52000 produces no visible injuries in the case of oaks, but results in an unfavorable action on assimilation. More sensitive kinds of wood, for example, beeches, manifest an appreciable retardation of the process of assimilation even with a ratio of acid to air of 1:300000.

RONZANI, ——. The influence of the respiration of caustic gases on the resistance to infectious diseases. Archiv f. Hygiene, vol. 67, 1908, pp. 287–366.

In investigating this problem Ronzani restricted himself to the action of chlorine sulphur dioxide, and nitrous oxid. His general conclusion is that prolonged breathing of noxious vapors, which in the case of chlorine, sulphur dioxide, and nitrous acid exceed the proportions of 0.002, 0.05, and 0.05 parts per parts of air, respectively, occasion in animals. (*a*) A gradual decrease in nutrition and a variation of the chief blood components; (*b*) a decrease in the production of specific antibodies and a lowering of the bactericidal strength of the lungs; (*c*) in the case of receptive animals a lowering of the power of resistance to infection; (*d*) in immune animals, receptivity for infection. Dogs, guinea pigs, and pigeons were used in the experiments. The methods were elaborate and carefully worked out. They may be summed up by saying that the animals were subjected to the vapors in question in wooden chambers with metal floors and after inhaling the gas for definite periods the following determinations were made: (1) The agglutinizing power of animals immunized against certain infections (typhoid, pneumococcus, haemolytic anthrax, tuberculosis); (2) the immunizing power of the blood serum of both the treated animals and control animals; (3) the bactericidal power of the lungs; (4) resistance of receptive animals to inoculation with virulent pathogenic germs; (5) resistance of receptive animals to inoculation with weakened pathogenic germs; (6) resistance of immune animals to inoculation with virulent pathogenic germs.

RUSTON, —— Air pollution by coal smoke and its effects on vegetation. Paper read at the Smoke Abatement Conferences, March, 1912. Trans., pp. 33–45. Abstracted in Jour. Roy. Sanitary Inst., vol. 33, pp. 433–435. This paper is practically a reprint of Crowther and Ruston, Jour. Agr. Sci., vol. 4, p. 25.

—— Influence of smoke on plant growth. Read before Manchester and Salford Smoke Abatement Exhibition and Conference. Report of the Smoke Abatement League, 1911, pp. 44–53; Rauch und Staub, vol. 2, pp. 93–98; abstracted in Chem. Trade Jour., vol. 49, p. 522; Chem. Abs., vol. 6, 1912, p. 419. States that smoke has a harmful action on vegetation, owing to both the soot and the acid components. To determine the effect of the free acids (sulphur dioxide) a

series of experiments on grass was undertaken. In these a number of grass test plats were grown under similar conditions, except for the rain water with which they were watered. In one series the plats were watered with neutralized rain water; in another with unneutralized, and in a third with unneutralized rain water from a district high in sulphur dioxide smoke content. The growth and life of the grass as well as its food value were unfavorably influenced by the SO_2. This factor in smoke also retards the growth of trees and inhibits the activity of soil bacteria, particularly the nitrifying organisms. The acidity of the waters used was as follows:

Data regarding water used in experiments.

Source.	Suspended matter.	Acidity.
	Pounds per acre.	*Pounds per acre.*
Hunslet	1,565	90
Leeds University	399	26
Headingley Hill	273	18.5
Weetwood Lane	147	11
Roundhay	90	None.

"It has been observed in Leeds that ash trees in those parts of the town with purer air often keep their leaves four and even six weeks longer than trees in parts of the city with worse air. For example, in the fall of 1908 it was established that in Roundhay where the air contains 90 pounds of suspended matter per acre, but on the other hand no acid, ash trees bore their full quota of leaves even as late as the 17th of November. At the same time, however, it was observed that in Weetwood Lane, where the air precipitates 147 pounds of suspended matter and 11 pounds of sulphuric acid per acre, all leaves had fallen off long before the end of October, and that only few trees carried any foliage on October 22. In Kirkstall, where 352 pounds of suspended matter and 8 pounds of sulphuric acid per acre were established, only one ash could be found on October 5 that carried foliage, and in Headingley, with 659 pounds of suspended matter and 11 pounds of acid per acre, all the leaves had fallen off from the ashes by this time. In Hunslet, where 1,565 pounds of suspended matter and 90 pounds of sulphuric acid are precipitated per acre, the leaves were removed from all ashes by September 18, while at the same time all the ashes in Roundhay bore foliage up to the beginning of November."

SABACHNIKOFF, ——. Action of sulphurous acid on pollen. Compt. rend. Soc. biologique, vol. 72, 1912, pp. 191–193; Chem. Abs., vol. 6, p. 1305. States that the flowering plants were placed under a bell jar containing a known mixture of air and sulphur dioxide. After the plants had been subjected to the action of the gas, the pollen was removed and allowed to germinate in incubators, solutions of saccharose being used as the culture medium. This air was saturated with water vapor, germination taking place at 25° under the influence of diffused light. The concentrations employed varied from 1:1000 to 1:300000, action lasting 3 to 48 hours. It was concluded that a concentration of 1 to 48000 acting for 48 hours is without effect, but that concentrations higher than 1 to 13000 destroy the germinating power if allowed to act for 3 hours. Poisoned pollen which is not killed develop abnormally.

SCHAEFER, ——. Contamination of the air of our cities with sulphur dioxide the cause of respiratory disease. Boston Med. and Surg. Jour., vol. 157, 1907, pp.106–110. Gives a fair review of the subject, but does not contain any original work. Experimental data quoted.

SCHROETER, E. Die Rauchquellen im Koenigreich Sachsen und ihre Einfluss auf die Forstwirtschaft. (The sources of smoke in the Kingdom of Saxony and their effect on forestry), Berlin, 220 pp. The table of contents is as follows:

I. Introduction. II. Methods of procedure (information obtained by circulars, etc.). III. Causes and effects of smoke damage—Sources of smoke in general; action of waste gases; chronic and acute injuries; coefficients of injury of typical industries; special action of sulphur dioxide; consequences in pine forests. IV. Smoke injuries in forests of Saxony and their sources. V. Preventative and curative methods. VI. Necessity of public regulations. VII. Conclusions. VIII. Supplement. (Maps, charts, tables, etc.)

SEIDELL, —— and MESERVE, ——. Gaseous impurities in the air of railway tunnels. Bull. 92, Hygienic Laboratory, United States Public Health Service, June, 1914. Contains a method for determining the sulphur dioxide content of atmosphere.

SOMMA, ——. Determination of the action of noxious gases on vegetation. Yearbook Tech. and Nav. Inst. at Bari (Italy), 1904.

SORAUER, PAUL. Die mikroskopische Analyse rauchbeschaedigter Pflanzen. (Microscopic analysis of smoke-injured plants.) Berlin, 1911. 58 pp.

——— Handbuch der Pflanzenkrankheiten. (Manual of Plant Diseases.) Third edition, in three volumes, Berlin, 1909–1911. Volume I treats of nonparasitic diseases, including those caused by sulphurous acid. See pp. 711–747.

——— Note on the anatomical analysis of plants injured by smoke. Landwirtschaftliche Jahrbuecher, vol. 33, 1904, pp. 585–664. Is restricted to a discussion of injuries caused by hydrochloric acid but with the article under the same title by the same author published in 1908 gives the complete method.

——— Notes on the anatomical analysis of smoke-injured plants. Landwirtschaftliche Jahrbuecher, vol. 37, 1908, pp. 673–710. Abstracted in Botanisch. Zentralbl., vol. 110, 1909, pp. 354–357. States that the work is a continuation of that reported in volume 33 of the Landwirtschaftliche Jahrbuecher (1904). The previous investigations were extended to the study of injuries to pines caused by smoke, among other factors being the influence of sulphur dioxide. The entire work presents a microscopical method for determining the specific causes of any injury suffered in any given instance. The proposed method is discussed in detail and is considered of great value as a supplement to chemical analysis.

STUTZER, ALBERT. Action of sulphurous acid upon plants. Deutsche landwirtschaftliche Presse, vol. 29, 1902, p. 725. Abstracted in Chem. Zeit. Repertorium, 1902, p. 327; Jour. Soc. Chem. Ind., vol. 22, 1902, p. 42. Treats of use of sulphur dioxide in aqueous solution for the purpose of investigating the injuries which might accrue from sulphite cellulose waste liquors.

TATLOCK, ——, and THOMPSON, ——. Damage to vegetation by sulphurous and sulphuric acids in the atmosphere. Analyst, vol. 39, 1914, pp. 203–210; abstracted in Jour. Soc. Chem. Ind., vol. 33, 1914, p. 610; Chem. Abs., vol. 8, p. 2559. States that in cases of injury to vegetation too much emphasis must not be placed on the sulphuric acid content of the injured plants. Analytical data on such plants are given.

VON RUŠNOV, PETER. Über die Festellung von Rauchschäden im Nadelwald (Effects of factory smoke on pine forests). Zentralbl. gasammte Forstwesen, vol. 36, June, 1910, pp. 257–268; Chem. Abs., vol. 5, 1911, p. 897; Experiment Station Record, vol. 23, p. 726. Calls attention to the serious damage to coniferous forests that occurs from factory smoke containing sulphur dioxide and sulphur trioxide. Various examples are cited, and the character and extent of the injuries, the age and kind of trees affected, the results of microscopic examinations, and chemical analyses of the injured trees are given.

VON RUŠNOV, PETER. The establishment of injuries by smoke in pine forests. Zentralbl. gesammte Forstwesen, 1910, pp. 310–330. Abstracted in Botanisch. Zentralbl., vol. 117, 1911, p. 487. States that the sulphuric acid content of the needles compared to that of healthy examples in the same locality is admirably suited for establishing the source of injury. The SO_2 content of healthy pine needles, for example, was 0.19–0.22 per cent, whereas those injured by smoke contained as much as 1.27 per cent.

WEIGEL, ——. A case of croupous pneumonia after breathing sulphur dioxide. Muenchner medizinische Wochenschrift, 1903, p. 1236. Gives the history of the case of a workman who inhaled concentrated sulphur dioxide fumes and died from croupous pneumonia within seven days. Small concentrations have an injurious effect. No definite figures are given. "The workman was engaged in sulphurizing hops. During this there was an excessive development of sulphur dioxide to which this workman was particularly exposed because he tried to empty the pan filled with an excessive amount of burning sulphur."

WERNER, ——. Smoke injuries. Oesterreich. Vierteljahrschrift f. Forstwesen, vol. 26, 1908, pp. 107–121.

WIDTSOE, J. A. Smelter smoke and agriculture. Bull. 88, Utah Agri. Coll. Exp. Sta., 1903. Little experimental work discussed. States that injuries from smelter fumes have been much exaggerated, and that fodder exposed to fumes is not injurious to cattle.

WIELER, A. Über unsichtbare Rauchschäden (Invisible smoke injuries). Zeitschr. f. Forst u. Jagdw., vol. 35, April, 1903, pp. 204–205. Abstracted in Zeitschr. f. Pflanzenkrankheiten, vol. 14, 1904, pp. 84–85. Author states that by invisible injuries are meant injuries that are not manifested to the naked eye by the destruction of leaf parts, the injuries being caused by the action of acid gases, chiefly sulphur dioxide, and result in decreased production of organic matter by lessening the assimilation of carbonic acid. In a direct experiment in a Wislicenus smokehouse in which carbon bisulphide was burned to sulphur dioxide, it was shown that with a concentration of 1 : 500,000 decoloration of the leaves of beeches takes place. Upon exposure to sunlight both change of color and death of many leaf parts soon became manifest. The effects on various other trees were also given.

——— Über unsichtbare Rauchschäden bei Nadelbäumen (Invisible smoke injuries to pine trees). Zeitsch. f. Forst u. Jagdw., vol. 29, September, 1897, pp. 512–529.

———. Casual relationships between injuries to vegetation and the products of combustion of coal. Rauch und Staub, vol. 1, 1911, pp. 248–255. States that in the past too much emphasis has been placed on the injuries caused by the presence of sulphur dioxide in the atmosphere. The results of Wieler's investigations would make it appear that the chief mode of action is the removal of lime from the soil by the sulphuric acid resulting from the oxidation of precipitated sulphur dioxide.

———. Indirect action on vegetation of smelter fumes and other acid gases. Address before Naturwissenschaftliche Gesellschaft zu Aachen, June, 1910. Author's abstract in Deutsche landwirtschaftliche Presse, vol. 37, pp. 871–872. Abstracted in Fuehling's landwirtschaftliche Zeit., vol. 60, p. 204. Brings forward new experimental proof of the author's theory that sulphur dioxide causes indirect damage by removing lime from the soil. In establishing sulphur dioxide injuries too much emphasis should not be placed on the sulphuric acid content of the plants in question.

———. Litigation on smoke injuries. Jahresbericht der Vereinigung der Vertreter der angewandten Botanik, vol. 6, 1908, pp. 47–72. Gives further experimental evidence in support of the author's theory of the removal of lime from soil exposed to sulphur dioxide.

WIELER, A. Litigation on the injuries caused by smoke. Jahresbericht der Vereinigung der Vertreter der angewandten Botanik. Abstracted in Zeitschr. f. Pflanzenkrankheiten, vol. 21, 1911, pp. 168–169. Gives new experimental evidence in support of the author's views on the action of sulphurous acid on soils.

——— Pflanzenwachstum und Kalkmangel im Boden. Untersuchungen ueber den Einfluss der Entkalkung des Bodens durch Huettenrauch und ueber die giftige Wirkung von Metallverbindungen auf das Pflanzenwachstum. (Plant growth and deficiency in lime in the soil. Investigations on the influence of removal of lime from the soil by smelter fumes and on the poisonous action of metallic compounds on plant growth.) Berlin, 1912, 237 pp. This is a continuation of the author's "Untersuchungen ueber die Einwirkungen schwefliger Sacure auf Pflanzen" published in 1905.

———. Recent work on the influence of acid gas on plants. Jahresbericht der Vereinigung der Vertreter der angewandten Botanik, vol. 3, 1904–1905, pp. 166–178. Abstracted in Botanisch. Zentralbl., vol. 105, 1907, pp. 109–111. Gives a critical review of the literature from 1903 to 1905, including author's own book, placing special emphasis on the effects of sulphur dioxide.

———. Smoke injuries which have received but little attention. Jahresber. der Vereinigung der Vertreter der angew. Botanik, 1903, pp. 62–78. Abstracted in Biedermann's Zentralbl. f. Agrikulturchemie, vol. 34, 1905, pp. 248–250; Botanisch. Zentralbl., vol. 95, 1904, p. 304. Author takes exception to the generally accepted view that sulphurous acid when injuring vegetation acts only on the leaves of the trees. There seems to be a definite action on the soil caused chiefly by acid precipitated by rain. In order to prove that the destruction of the green color of the leaves of beech trees, and the fact that they turn red are both due to sulphur dioxide, two beeches were grown in a smoking chamber (volume 7 cubic meters) which contained dilute sulphurous acid produced by the combustion of carbon bisulphide with alcohol. Fumigation took place from May 31 to July 10, and caused partial bleaching of the leaves. Upon exposure to sunlight, however, the leaves turned reddish-brown, several dying.

———. The action of acid smoke gases on vegetation and soil. Address delivered at May, 1913, meeting of Naturhistorischer Verein der preussischen Rheinlande und Westfalens und Niederrheinisch Geologischen Vereins. Abstracted in Glueckauf, 1913, p. 836; Rauch und Staub, vol. 3, p. 366.

———. The action of sulphurous acid on plants. Berichte deutsch. botanisch. Gesell., vol. 20, 1902, pp. 556–566. Abstracted in Botanisch. Zentralbl., vol. 92, 1903, p. 205; Zeitschr. f. Pflanzenkrankheiten, vol. 14, 1904, pp. 83–84. The top of the plant under examination passed through a horizontal ground glass plate with a hole 6 to 7 cm. in diameter. Over the plant was placed a stoppered bell jar of a capacity of about 27 liters, which fitted snugly on the glass plate. The rubber stopper of the bell jar was three-holed. Through one hole passed a mercury manometer, and the two other holes served for the introduction and removal of the gas. The air passed through a gasometer, and after absorption of both carbonic acid and the water vapor it was led into a flask containing sulphuric acid and was then saturated with carbonic acid by means of dripping soda solution. From here the air passed into a small container with H_2SO_4 where it became saturated with sulphurous acid by means of dripping Na_2SO_3. After passing through a mixer it passed into the bell jar from the top and was drwan out at the bottom. After leaving the bell the air passed through a worm or worms filled with standard $Ba(OH)_2$. The source of light was electricity. Experiments were also conducted with strong incandescent burners. The electric light, however, gave greater assimilation values. The air contained 0.1 of volatile CO_2. The experiment lasted 5 to 6 hours. Under the influence of SO_2, assimilation was decreased, but different plants, even of the same species, were of different sensitiveness. Dilute

concentrations were used. In addition, beeches were subjected to SO_2 fumes in a glass smokehouse. The concentration was 1:500000, but during part of the experiments the concentration was higher because of a defect in the lamp burning the CS_2. Plants were kept in this for about six weeks and then eight days after the lamp had been extinguished. The plants were then taken out and submitted to the action of sunlight. The leaves had changed slightly because of being kept in the smokehouse. After being in sunlight for a few days, the injuries became manifest, parts dying off and turning yellow.

WIELER, A. The importance of air analysis in smoke litigation. Jahresbericht der Vereinigung der Vertreter der angewandten Botanik, vol. 4, 1906, pp. 63–78. Gives a method for determining the sulphur-dioxide content of the atmosphere. "By means of an aspirator the accurately measured volume of air is drawn through the absorbing solution. For this purpose a solution of potassium carbonate was used."

———. The literature of smoke injuries of recent years. Jahresber. Verein. der Vertreter der angew. Botanik, vol. 6, 1909, pp. 73–102. Reviews various articles of the preceding year.

———. The removal of lime from soils through smelter smoke. Wiener landwirtschaftliche Zeit., vol. 63, 1913, p. 135; Chem. Abstracts, vol. 7, p. 1779. States that experiments conducted in the vicinity of the smelters at Claustal show that the damage from smelter fumes is of two kinds: (1) Injury to the leaves, and (2) removal of $CaCO_3$ from the soil.

———. Untersuchungen ueber die Einwirkung schwefliger Saeure auf die Pflanzen. (Investigations on the action of sulphurous acid on vegetation.) Berlin, 1905, 427 pp. This work includes a survey of past work and presents the results of much original investigation.

WINKLER, ——. Vortraege und Abhandlungen ueber Abgase und Rauchschaeden. (Addresses and articles on waste gases and smoke injuries.) Berlin, 1913, 90 pp.

WISLICENUS, H. Die Grundlagen technischer und gesetzlicher Massnahmen gegen Rauchschaeden. (Principles of technical and legal measures against smoke damage.) Berlin, 1908, 80 pp. Reviews the problem, giving the limits of injury and the various means of prevention.

——— Experimental smoke damage in the experimental smokehouse at Tharandt. Report of the 57th Congress of the Saxony Forestry Society. Trans., 1913, pp. 78–93. Abstracted in Chem. Zentralbl., No. 1, 1914, p. 1897. The experiments were carried out with both sulphur dioxide and silicon fluoride. The former showed that the present limits of concentration (1 : 500000) are too low. Sulphur dioxide affects assimilation. According to the experiments of the author, a cessation of assimilation by removal of light makes the plant entirely unsusceptible to the action of SO_2 in the daytime, even in summer.

——— Ueber die Abgasfrage und ihre Bekaempfung. (Waste gases and their prevention.) Dresden, 1911.

PUBLICATIONS ON MINERAL TECHNOLOGY.

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TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

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DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

VAN. H. MANNING, ACTING DIRECTOR

MANUFACTURE AND USES OF ALLOY STEELS

BY

HENRY D. HIBBARD

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The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

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MANUFACTURE AND USES OF ALLOY STEELS.

By Henry D. Hibbard.

INTRODUCTION.

The object of this report is to give briefly information of present value relating to the manufacture and uses of the various commercial alloy steels, with the hope of stimulating the demand for such steels and extending their practical use. The report is issued by the Bureau of Mines as a contribution to the increase of efficiency in the preparation and utilization of the mineral resources of the United States.

Alloy steels are included in the so-called special steels, but as the latter term is often used in the mills to designate broadly any steels intended for purposes other than those served by the regular product, it has seemed best to use the more specific term of alloy steels in this report.

Alloy steels are bringing about a series of revolutions in various industrial fields in which steel plays an important part. Most elements that could be procured in sufficient quantity have been alloyed with iron in various proportions, either alone or in combination with others, in the search for useful alloy steels. Those steels that have gained and maintained for themselves a place in current use are discussed in this report. Some of them have had an ephemeral life of usefulness which would no doubt have been prolonged had not some other more satisfactory steel been developed.

Probably the first useful alloy steel was Mushet's self-hardening tungsten tool steel, patented in 1868. Fifteen years later chromium steel, really containing chromium, was struggling for recognition for some purposes, the chief of which was for the manufacture of solid shot for piercing armor. In both of these steels the effect of the alloying element as used was in a way proportional to the amount contained. In 1882 Hadfield made his epoch-making discovery of manganese steel and demonstrated that in iron metallurgy it is not safe to take for granted anything as to the properties of an alloy of iron with other elements, basing one's opinion on past experience and knowledge, and that the effect of an alloying element may not be proportional to its content. The development of useful nickel

steels followed in a few years and the field thus opened has since then been worked by many able and zealous men, with results of great importance and value.

DEFINITIONS.

Definitions of terms used throughout this report are presented below:

Simple steel, often called "carbon steel," consists chiefly of iron, carbon, and manganese. Other elements are always present, but are not essential to the formation of the steel, and the content of carbon or manganese, or both, may be very small.

Alloy steel is steel that contains one or more elements other than carbon in sufficient proportion to modify or improve substantially and positively some of its useful properties.

Simple alloy steel is alloy steel containing one alloying element, as for example, simple nickel steel.

Ternary steel is alloy steel that contains one alloying element, the term being synonymous with "simple alloy steel."

Quaternary steel is an alloy steel that contains two alloying elements such as chromium-vanadium steel.

Complex steel is an alloy steel containing more than two alloying elements, such as high-speed tool steel.

Alloy-treated steel is a simple steel to which one or more alloying elements have been added for curative purposes, but in which the excess of the element or elements is not enough to make it an alloy steel.

Raw steel is steel as cast, either an ingot or casting.

Natural steel is steel in the condition left by a hot-working operation, and cooled in the open air.

Normalized steel is steel that has been given a normalizing heat treatment intended to bring all of a lot of samples under consideration into the same condition.

Annealed steel is steel that has been subjected to an annealing operation.

Hardened steel is steel that has been hardened by quenching from or above the hardening temperature.

Tempered steel is steel that has been hardened and subsequently tempered by a second lower heating.

These definitions are based on the definition of steel that states that steel must be usefully malleable. The definitions of alloy steels do not include effects which are negative, or the prevention or cure of ills which the steel might possess were the alloying element or elements not added.

An iron alloy is not herein considered as useful unless it presents some useful property or modification of a property not offered to the same degree by a simple steel.

The definition of alloy steel given does not agree with that of all writers on the subject of mixtures of iron with other elements than carbon; but it does agree with that of some who have been careful enough when considering the whole range of elements to designate them as alloys, such as silicon-iron alloys and chrome-vanadium alloys, the range covering the useful alloys or steels as well as those in which the alloying element is added for curative purposes and others that have only a scientific interest.

Elements other than carbon may be desired in steel, and therefore be added to or permitted to remain in it for three distinct purposes, as follows:

1. To give the composition desired and to cure in simple steels some ills or defects that the final product might otherwise possess.

2. To make alloy steels. Such elements are manganese, silicon, tungsten, nickel, chromium, vanadium, cobalt, and others of less importance.

3. To make alloys which, though they excite only a scientific interest, form a great part of the whole field of iron metallurgy. Many a one of these alloys would have a commercial value if another alloy were not known that meets particular requirements more satisfactorily either as to efficiency or as to cost or both.

The various additions of the element manganese to iron illustrate well the three purposes of alloys as above specified. A moderate amount, usually less than 1½ per cent, is added to molten steel made by an oxidation process (pneumatic or open hearth) to prevent red-shortness. A much larger amount is added to make commercial manganese steel, which should contain 11 to 14 per cent of manganese. Outside of these limits, a great number of manganese-iron alloys may be made, most of which have only a scientific value, though the number of useful ones is always liable to be extended as new requirements and methods of manufacture and treatment arise. Simple commercial steels containing between 1.5 and 2 per cent of manganese are made, and manganese steels containing less than 11 per cent manganese are useful for certain purposes; but the manganese content of the great bulk of the steels made is within the limits given.

The total number of possible alloys of iron with varying proportions of other elements is of course practically infinite. So, indeed, is the number of useful alloys, though they form only a small fraction of the whole number.

This report deals exclusively with alloy steels, as defined above, in which the alloying element or elements modify directly, positively, and usefully some of the properties of the products.

LIST OF USEFUL ALLOY STEELS.

The eight alloy steels named below in the chronological order of their introduction are considered to meet this requirement:

1. Simple tungsten steels.
2. Simple chromium steels.
3. Manganese steel.
4. Simple nickel steels.
5. Nickel-chromium steels.
6. Silicon steels.
7. High-speed tool steels.
8. Chromium-vanadium steels.

The first four and the sixth of these are ternary steels, the fifth and eighth are quaternary, and the seventh is of complex composition. Some of these steels may be treated while molten by the addition of a purifying or solidifying element or elements in such a small quantity as not greatly to affect the final properties. Thus a small amount of titanium, aluminum, or vanadium may be added to a chromium or nickel steel and hardly appear in the final analysis. Such a result is seen in the alloy-treated steels.

ALLOY-TREATED STEELS.

Alloy-treated steels need be only briefly alluded to here. The method of manufacturing all steels made by the oxidation processes involves the presence in suspension or solution of harmful amounts of oxygen or oxides, and before the metal is cast means must be taken to lessen the oxygen or oxide content to or below an allowable maximum. One or more of certain elements having at steel-melting temperatures a stronger affinity for oxygen than iron has, are added to the molten metal. The oxygen leaves the iron to seize such added elements, forming new products insoluble in the iron, which in time are precipitated, gather together, and leave the metal.

Such unfinished steel also contains in solution a quantity of gases which require to be decomposed or kept in solution, for, if not, when the steel is solidifying, part of the gases will leave it and part will be imprisoned in the metal and form gas holes, of the variety commonly called blowholes. The addition of certain elements to the metal tends to prevent the separation of the gases.

Further there is a tendency of certain of the ingredients of steel to collect or segregate in an injurious way in the upper central part of a large ingot or casting, but the addition of certain elements lessens this tendency.

Elements that are added to prevent, minimize, or cure these ills are manganese, which is the most important, silicon, aluminum, titanium, vanadium, and others of less importance. The effects

aimed at are therapeutic and though real and valuable, are mostly negative rather than positive; that is, effort is made to cause the steel to be free from some or all of the defects cited.

The proportions of these elements added are, generally speaking, only enough to cure the defects to be removed or counteracted, with a suitable excess to reasonably assure such a result in view of the uncertainties and irregularities of steel making. The excess of any of the elements named has indeed some effect on the final properties of the steel, but not enough to put the product in the class of the alloy steels. Steels so treated are considered as alloy-treated steels, they being simple steels, outside the subject of this paper, as the alloying elements do not give new or modified properties of important commercial value.

Some alloying elements are added to simple steel in such proportions as to produce only a curative effect, and the product can not definitely be classified as a simple or an alloy steel, as can be done when a rather large excess of the element is added. The elements vanadium and silicon are examples, both being added to cure ills in the steel, and an excess of either causes the physical properties of the steel to vary to some extent. Both are used also in undoubted alloy steels that have unique properties,which would not be anticipated from the observation of the effect of a moderate excess of either in a simple steel.

Crude alloys of the alloying elements that are used as ingredients in steel making and are not useful themselves in their crude state are not herein considered.

THE USES OF ALLOY STEELS.

With few exceptions all alloy steels are heat treated for use, the treatment developing in them the high physical properties they are capable of possessing. No general law regarding the effects of heat treatment of alloy steels can be laid down. Some steels when quenched from a high heat are hardened and others are softened, the latter being generally those with the higher contents of certain of the alloying elements. In respect to the effects of heat treatment each steel is considered by itself.

Developments in the manufacture of alloy steel and in the heat treatment of steel have occurred somewhat simultaneously during the past 30 years, and care is needed lest the benefits gained from one be confounded with those afforded by the other. The highest merit is obtained from the adoption of both developments together—that is, the use of heat-treated alloy steels. Usually heat treatment has contributed more to the superior properties of the metal than has the use of alloys.

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The alloy steels discussed in this report are considered as regards their value for structural, cutting, or electrical purposes.

Steel used for structural purposes is taken to include that used for the stationary as well as the moving parts of structures and machines, including bridges, buildings, vehicles, machine tools (except the cutting tools), armor plate, ships, ores involving resistance to abrasion or corrosion, and wire, except electrical wire, and in general all steel not used in the other two fields.

Steel used for cutting purposes includes that employed to form an actual cutting edge and that used in projectiles for war.

Steel for electrical purposes is used in magnets, core steel, non-magnetic articles, and electrical-resistance devices.

No steel suitable in a commercial sense for two of these purposes is made, though some steels might be used for more than one purpose if a better kind for the other specific purpose were not known; thus a fair tool steel might be made of some of the harder structural steels, and a fair magnet might be made of some of the tool steels.

The effects of the alloying elements in alloy steels are various; thus nickel increases the elastic limit as compared to tensility; chromium increases the hardness of quenched steel; and manganese destroys magnetic susceptibility—effects all of which are valuable for certain purposes.

MANUFACTURE OF ALLOY STEEL.

Alloy steels are made by any of the steel-making processes, that is, by any of the variations of the pneumatic processes, by the acid or basic open hearth, by the electric furnace, and by the crucible. For each of the various purposes, however, the practice is more limited, the general rule being of course that the cheapest process is employed that will yield a product satisfactory for the purpose in view.

All alloy-steel ingots or castings should be made sound and with full tendency to pipe. Soundness, which means freedom from gas holes, is, generally speaking, a necessary requirement in order that the product may be sound, as almost any of the alloying elements interferes with or prevents the welding of steel that contains that element so that any contained gas holes in ingots will not be welded up by hot working. Therefore they may, if near the surface, be opened to the air by scaling in heating or by forging and rolling and then be oxidized within and form seams. Chromium and nickel more than other alloying metals prevent welding in steel.

Pipe in the ingot may be shortened in length by casting the ingot with the larger end up, or it may be avoided if the ingot when so cast is squeezed laterally, or if the top is maintained in the molten state until the remainder of the ingot is solid. If neither of these means

is employed enough of the top of the ingot must be discarded to get rid of any objectionable pipe. Whether any pipe is permissible depends on the use to be made of the steel, there being many uses for which steel containing a pipe is adapted, or a hole may even be drilled where the pipe would naturally be as is often done to favor heat treatment in massive articles.

The amounts given in this report of the different steels produced in the United States have for the most part been determined by indirect means. They are therefore not exact, but are, it is believed, near enough to the truth to warrant presenting them.

The temperatures are given in both centigrade and Fahrenheit degrees.

Alloy steels and other alloys of iron with other elements have been discussed by numerous writers chiefly in their general or purely scientific aspects.

The selected bibliography, at the end of each chapter, relating to the different alloy steels is intended to be limited to articles that bear upon the useful steels. Many of the articles themselves have bibliographies more or less complete. The bibliography is arranged chronologically.

STRUCTURAL ALLOY STEELS.

GENERAL CONSIDERATIONS.

Structural steels, whose fields of use have already been noted, have some attributes in common, which makes it worth while to consider them collectively to a certain extent. These steels are working great improvements in the production of structures for various purposes, especially where the saving of weight or increase of strength or both are important, the most conspicuous example being undoubtedly the automobile industry. Heat-treated alloy steels with double or treble the strength of the simple steels they replace and with as great or greater reliability are now in regular and most advantageous use. In common with other alloy steels, structural alloy steels owe a part of their superior properties to the presence of the alloying element but usually far more to heat treatment when it can be given to them. In automobiles the use of alloy steels is generally not advised unless the steels are heat treated, as the gain from their use in the natural or untreated state does not compensate for the increased cost.

Most structural alloy steels are therefore used in the heat-treated condition, when the articles made of them are, like automobile parts, not too bulky or massive. Large pieces like nickel-steel rails and nickel-steel members of bridges are used without heat treatment, the advantages of increased strength and ductility that the metal possesses being due solely to the presence of the alloying element.

The difficulties attending the heat treatment of large steel parts that are bulky for their weight are holding back their general introduction. They require, as nearly as is practicable, to be uniformly heated, uniformly cooled in quenching, and afterward, when cold, to be made true to form, as the quenching operation, however carefully done, usually leaves them warped or twisted. No doubt, in time, means will be found to overcome these drawbacks and such pieces as rails, and bridge members of alloy steels will be used regularly in the heat-treated condition. A compact object like an armor plate, though very large, may be quenched without unmanageable warping because of its simple shape. The difficulty in making straight and true such an article as a heat-treated rail of pearlitic alloy steels lies largely in the springiness of the treated metal. It is not easy to give it the correct amount of set needed to counteract or obliterate a crook, bend, or twist that may result from quenching. Yet this is necessary when the piece must be straight or true to shape. Stretching slightly beyond the elastic limit as is done to some thin steel sheets and relatively small bars to straighten them might be efficacious, but is not to be easily done with a piece of such irregular cross section as a rail.

The effects of heat treatment are so great that a certain steel may be given a very wide range of properties, depending on the treatment, and any desired set of properties within that range may be obtained solely by varying the heat treatment. The principal variant is the degree of the second heating. The lower this is, the stronger and stiffer the steel, and the higher, the weaker and more ductile it is.

This effect of heat treatment on steel is illustrated by a table published by a producer giving the results of 40 tensile tests made from one heat of steel, each test piece having had a different heat treatment. Five, which cover the range, are given in the table below.

Results of tensile-strength tests of 5 pieces of steel each receiving a different heat treatment.

Tensility.	Elastic limit.	Elastic ratio.	Elongation in 2 inches.	Contraction of area.
Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
84,850	50,500	60	28	67.5
120,975	90,000	74.5	14.5	51
166,950	157,500	94	12.5	44
205,600	200,000	97	13	48.7
240,975	225,000	93	9	20.5

Analysis of the original steel showed C, 0.25; Mn, 0.50; Cr, 1.07; and V, 0.17 per cent, but similar results could be obtained with a variety of compositions.

For making small parts that must be true and well finished the structural alloy steels are generally heat treated before they are machined, and this requirement prevents the use in such parts of

steel of the highest strength attainable because steel having that strength is not commercially machinable. Generally speaking, any part that is to have an elastic limit of more than 100,000 pounds per square inch must be treated after having been machined, not before, because most steels having a higher elastic limit than that are too hard to allow machining by commercial processes, though chromium-vanadium steels with an elastic limit of 150,000 pounds per square inch are claimed to be machinable, that is, they may be cut with high-speed steels at a profitable rate. An elastic limit of 100,000 pounds or more per square inch can be imparted to steel only by heat treatment, as no untreated steel of a commercial grade will have so high a limit.

Some of the makers of structural alloy steels are publishing for each of their steels a graph showing the physical properties the steel will have when hardened and then drawn to different temperatures. Of course, the graphs give ex parte information which is subject to confirmation before acceptance, but the plan is excellent as giving the most information in the least space. Similar graphs of many alloy steels prepared by consumers are expected to be soon available for comparison. From these graphs a new user of these steels may choose the properties he desires and specify the steel he wishes, making some allowance of course (say 10 per cent) for the uncertainties of manufacture and treatment. The steel maker or treater, to be reasonably sure of meeting the requirements, will aim to exceed the properties specified, and the net result will usually be that the steel will have practically the properties desired.

The tables of properties given later show how much more the properties possessed are imparted by treatment than by composition.

The size or massiveness of the article has a great effect on the results obtained by any given heat treatment. The greater the mass the lower the qualities, though not in exact proportion. Thus the mass must always be considered in connection with the properties desired, and the composition and heat treatment prescribed must be modified accordingly, though even then the effect of mass may be only partly compensated for.

The modulus of elasticity of many, if not all, structural alloy steels in common with other steels is not changed much by heat treatment or variations in composition [a] and is usually between 28,000,000 and 30,000,000 pounds per square inch; that is, the modulus of the steel in its annealed, hardened, and tempered condition remains practically unchanged. The following table was compiled from data given by Landau.[b]

[a] Landau, David, Influences affecting the fundamental deflection of leaf springs: Bull. Soc. Automobile Eng., vol. 5, March, 1914, p. 430.

[b] Landau, David, op. cit., pp. 431–434.

Moduli of elasticity of some alloy steels.

Composition of steel.								Modulus.
C.	Si.	Mn.	P.	S.	Cr.	Ni.	V.	
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
0.50	0.13	0.82	0.01	0.02	1.25	.....	0.14	29,240,000
.47	1.83	.70	.01	.01	.....	.....	.....	28,950,000
.48	.16	.44	.01	.01	.98	2.02	.....	28,840,000
.30	.19	.64	.01	.01	.....	3.25	.18	28,260,000
.25	.21	.74	.01	.01	.....	3.55	.....	28,170,000
.24	.21	.46	.01	.02	.96	2.02	.....	28,200,000
.25	.16	.50	.01	.....	1.05	.....	.16	30,158,000

Because of the unchangeability of the modulus of elasticity the stiffness or rigidity of steel within the elastic limit is not changed either by heat treatment or the presence of any of the alloying elements, except perhaps manganese in manganese steel and nickel in high-nickel steels.

Heat treatment does increase the elasticity, however, so that a piece of heat-treated steel may return to its original form after having endured a stress that would have permanently deformed it in its untreated condition; that is, it is given some of the springiness of heat-treated springs.

Many of the structural steels, particularly those used in automobile manufacture, have a great endurance against fatigue when subjected to repeated alternating stresses. The heat treatment increases their durability in this test even more noticeably than it does the properties determined by the tensile test.

SELECTED BIBLIOGRAPHY.[a]

GENERAL ARTICLES DEALING WITH TWO OR MORE ALLOY STEELS.

METCALF, WILLIAM. Alloy steels. Proc. Am. Soc. Test. Mat., vol. 4, 1904, pp. 204–214.

GUILLET, LÉON. Les aciers spéciaux. 2 tomes, Paris, 1904–1905; also in Rev. mét., t. 1, 1904; t. 2, 1905.

GRENET, L. Note sur la trempe de l'acier. Bull. Soc. l'ind. min., t. 4, sér. 4, 1905, pp. 973–999.

NOBLE, H. Fabrication de l'acier. Paris, 1905, pp. 543–563.

GUILLET, LÉON. Etude industrielle des alliages métalliques. 2 tomes, Paris, 1906.

——— The industrial future of special steels. Iron and Steel Mag., vol. 11, February, 1906, pp. 89–95.

——— Quaternary steels. Jour. Iron and Steel Inst., 1906, pt. 2, pp. 1–141.

HOWE, H. M. Iron, steel, and other alloys. 2d ed., 1906.

LEDEBUR, A. Handbuch der Eisenhüttenkunde. Leipzig, 1906, pp. 348–399.

CAMPBELL, H. H. The manufacture and properties of iron and steel. 4th ed., 1907, pp. 343–391. Describes the influence of certain elements on the physical properties of steel.

[a] This bibliography and those at the end of subsequent chapters were compiled by the United Engineering Library, 29 West Thirty-ninth Street, New York City. The references are arranged chronologically.

FAY, T. J. Special auto steel. Proc. Am. Soc. Mech. Eng., vol. 28, June, 1907, pp. 1745–1777.

HAYNES, ELWOOD. Material for automobiles. Trans. Am. Soc. Mech. Eng., vol. 29, 1907, pp. 209–216.

LAKE, E. F. Heat treatment of alloyed steels. Am. Machinist, 1907, vol. 30, pp. 152, 196, 289.

——— Steels used in automobile construction. Am. Machinist, vol. 30, March 14, 1907, pp. 376–382.

GUILLET, LÉON. Special alloy steels and their mechanical applications. Eng. Mag., vol. 36, October, 1908, pp. 65–75.

RÉVILLON, LOUIS. Les aciers spéciaux au salon de l'automobile. Rev. mét., t. 5, February, 1908, pp. 53–68.

TURNER, W. L. The static and dynamic properties of steels. Iron Age, vol. 82, July 2, 1908, pp. 53–55.

GIESEN, WALTER. The special steels in theory and practice. Carnegie Scholarship Mem., Iron and Steel Inst., vol. 1, 1909, pp. 1–59.

GUILLET, LÉON. Les aciers spéciaux industriels. Rev. mét., t. 6, June, 1909, pp. 810–813.

LAW, E. F. Alloys and their industrial applications. London, 1909, 269 pp.

LONGMUIR, PERCY. High-tension steels. Jour. Iron and Steel Inst., pt. 1, 1909, pp. 383–403. Gives results of tests of nickel steels, nickel chromium, and chromium vanadium steels.

MATHEWS, J. A. Alloy steels for motor-car construction. Jour. Franklin Inst., vol. 167, May, 1909, pp. 379–397.

——— The nature and treatment of alloy steels. Iron Age, vol. 83, Jan. 7, 1909, pp. 24–26.

PORTEVIN, A. M. Contribution à l'Etude des aciers spéciaux ternaires. Rev. mét., t. 6, December, 1909, pp. 1164–1303. Carnegie Scholarship Mem., Iron and Steel Inst., vol. 1, 1909, pp. 230–264. Includes bibliography.

GUILLET, LÉON. Special steels. Iron Trade Rev., vol. 46, Feb. 3, 1910, pp. 367–369. Translated from a paper read before the International Association for Testing Materials.

HAENIG, A. Der Konstruktionstahl und seine Mikrostruktur, unter besonderer Berücksichtigung des modernen Automobilstahls. Berlin, 1910.

SOUTHER, HENRY. The selection and treatment of alloy steels for automobiles. Jour. Franklin Inst., vol. 170, December, 1910, pp. 437–450.

——— Specifications for materials—specifications for steel. Trans. Soc. Automobile Eng., vol. 5, 1910, pp. 168–175.

——— Notes and instructions referring to materials specified hereinbefore. Trans. Soc. Automobile Eng., vol. 5, 1910, pp. 176–202.

——— Alloy steels for railroad use. Am. Eng. and R. R. Jour., vol. 85, March, 1911, pp. 95–98. Abstract of paper read at joint meeting of the Engineering Club and Altoona Railroad Club.

HARBORD, F. W., and HALL, J. W. The metallurgy of steel. 4th ed., London, vol. 2, 1911, pp. 387–417. Discusses special steels or steel alloys.

LAKE, E. F. Alloy steel for automobiles. Automobile, vol. 24, June 29, 1911, pp. 1436–1440.

SANDELIN, FOLKE. Specialstal för Konstruktionsändamål. Stockholm, 1911, 173 pp. Includes a bibliography. Paper printed also in Jern Kontorets Annaler, vol. 66, 1911, p. 524.

STOUGHTON, BRADLEY. The metallurgy of iron and steel. 1911, pp. 389–411, 514–516. Discusses alloy steels and presents a bibliography.

INTERNATIONAL RAILWAY CONGRESS. The use of steel; special steels. Bulletin, vol. 25, August, 1911, pp. 849–881. Report and discussion.

EDWARDS, E. T. Recognizing alloy steels by ingot structure. Iron Age, vol. 89, Feb. 15, 1912, pp. 399–402.

TRANSACTIONS OF THE FARADAY SOCIETY. Magnetic properties of alloys; symposium. Vol. 8, 1912, pp. 94–219.

MARS, G. Die Spezialstähle; ihre Geschichte, Eigenschaften, Behandlung und Herstellung. Stuttgart, 1912.

ROBIN, FELIX. Traité de métallographie. Paris, 1912.

SAUVEUR, ALBERT. The metallography of iron and steel. 1912. 386 pp.

SOCIETY OF AUTOMOBILE ENGINEERS. Fourth report of the iron and steel division. Revised notes and instructions referring to materials specified. Transactions, vol. 8, pt. 2, 1913, pp. 7–50. Includes a bibliography.

HUDSON, O. F., and BENGOUGH, G. D. Iron and steel; an introductory textbook for engineers and metallurgists. London, 1913.

DEL MAR, ALGERNON. Wrought iron and steel for stamp-mill parts. Min. and Eng. World, vol. 40, April 11, 1914, pp. 687–693.

HALL, J. H. The steel foundry. 1914. 271 pp.

LANDAU, DAVID. Influences affecting the fundamental deflection of leaf springs. Bull. Soc. Automobile Eng., vol. 5, March, 1914, pp. 428–464.

SIMPLE TUNGSTEN STEEL.

Mushet's air-hardening steel, the first of the alloy steels, may be considered as a simple tungsten steel though it contained so much manganese (about 2 per cent) that it might with some reason be classed as a quaternary steel, as it contained also about 2 per cent of carbon and 6 per cent of tungsten. The manganese was essential to give the self-hardening property. The steel is now becoming obsolete, having had a useful career and having formed an indispensable link in the development of the high-speed tool steels discussed later.

Tungsten is very heavy, its specific gravity being, according to recent determinations, about 19.3, and it is the most infusible substance known except carbon and, perhaps, boron. These properties have some effect on the production of tungsten steel.

MANUFACTURE OF TUNGSTEN STEEL.

Tungsten steel is generally, if not always, made by the crucible process. The pots are charged cold by packing in the materials, the tungsten being placed at the top to counteract in a measure its tendency to settle because of its high specific gravity. If this tendency operated unchecked there might be at the bottom of the pot a rather infusible mush of high-tungsten alloy which would not pour out, and if it did the ingot would have an irregular composition because of the uneven distribution of the tungsten.

The steel is melted and then "killed" in the crucibles by holding them in the furnace for 30 or 40 minutes after the charge has melted, until the steel ceases to bubble or work and lies dead in the pot.

The pots are sometimes cast singly or doubly by hand pouring or collectively by means of a ladle into which all the pots of a furnace charge are emptied. Good tungsten steel makes remarkably sound

solid ingots, except for the pipe, though tungsten itself is not considered to aid in removing or controlling either the oxides or the gases. It is added solely for its effect on the finished and treated steel.

This lack of power of tungsten to deal with oxides and gases arises no doubt from its low calorific power, its heat of combustion being given (with qualification) as about 1,000 calories, whereas iron burned to Fe_3O_4 gives 1,612 calories.

METHOD OF WORKING.

Simple tungsten steels of commercial grades are heated, forged, and rolled in much the same manner as other high-carbon steels, presenting no special problems or difficulties.

PROPERTIES AND USES.

Simple tungsten steel is at present chiefly used in permanent magnets for electric meters, in small dynamos, and hand use, for which it has been used for 30 or 40 years. The consumption in 1913 is thought to have been between 5,000 and 6,000 tons. This steel contains about 0.6 per cent of carbon and 6 per cent of tungsten. Some has been made in recent years containing 0.2 to 0.3 per cent of vanadium, chromium, or molybdenum which were considered at the time to give greater retentivity to the steel, but those ingredients are now generally held to be of no practical value, adding nothing to the fitness of the steel for its purpose.

Some buyers of magnet steel do not specify composition but only performance, that is, what magnetic properties the steel must have.

To make permanent magnets retain their magnetism as much as possible they are made very hard by heating and quenching. They are then magnetized, and if they are to be used for electric meters they are seasoned by a treatment involving protracted heating to 100° C. (212° F.) to make their magnetism as nearly constant as possible.

A variety of tungsten steel containing about 1 per cent of carbon and 3 to 4 per cent of tungsten is made and used as a tool steel for taking finishing cuts on iron and steel in the machine shop. It acts more like a simple steel than a self-hardening steel, as it requires to be hardened by quenching in water and then drawn in the same general way that simple steels have been drawn, presumably for thousands of years. It will cut at a higher speed than a simple steel, say 40 feet per minute on steel having a tensile strength of 80,000 pounds per square inch, and is also more durable.

The presence of tungsten in steel is generally stated to lower the fusion point of the steel. Mars [a] gives a table of fusion points of

[a] Mars, G., Die Specialstähle; ihre Geschichte, Eigenschaften, Behandlung und Herstellung. Stuttgart, 1912.

tungsten steels with contents of tungsten ranging from 0.5 to 17 per cent, from which he concludes that tungsten lowers the fusion point. However, when his results are corrected for the lowering effects of the contained carbon, silicon, and manganese doubt arises as to the correctness of his conclusion. Thus, a steel containing 0.66 per cent C, 0.03 per cent Si, 0.04 per cent Mn, and 3.11 per cent W fused at 1,488° C. The carbon would lower the fusion point about 60° C., and the silicon and manganese slightly, so that the plain iron-tungsten alloy should have a fusion point a little above 1,548° C., which is about 20° C. above that of pure iron. Seemingly this is the effect of 3.11 per cent tungsten.

The erosion of the bore of cannon by the powder gases is held to depend largely on the fusion point of the metal of the tube or liner, the higher the point the greater being the resistance to erosion. So it has been found that the nearer the metal comes to being pure iron the higher its fusion temperature and the better it resists erosion, but the strength required compels a certain amount of hardening and strengthening elements to be present in the steel. Tungsten raises the strength and possibly the temperature of fusion and so has been employed for the tubes of cannon, particularly by the Government of Austria. Arnold and Read [a] found that steel with 0.71 per cent carbon and 5.4 per cent tungsten had in the annealed state a tensility of 88,900 pounds per square inch, an elastic limit of 60,200 pounds, an elongation of 20 per cent, and a contraction of area of 34.7 per cent, values that compare favorably with those of the steels usually employed in the manufacture of cannon.

They give data regarding a series of annealed tungsten steels as follows:

Data regarding annealed tungsten steels.

Composition.							Tensile properties.				Condition when turned.
C.	W.	Si.	Mn.	P.	S.	Al.	Tensility.	Yield point.	Elongation in 2 inches.	Contraction of area.	
P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*	
0.73	2.4	0.11					84,200	48,100	20.5	31.5	Moderately tough.
.71	5.4	.11					88,900	60,200	20.0	34.7	Tough.[f]
.70	9.7	.04					126,100	90,000	14.0	22.1	Very tough.
.73	15.0	.03	(b)	(c)	(a)	(e)	98,500	.....	25.0	43.3	Do.
.72	21.1	.06					104,300	57,300	20.5	39.2	Very tough, slightly hard.
.67	26.3	.06					110,600	.....	9.0	11.4	Do.

[a] Arnold, J. O., and Read, A. A., The chemical and mechanical relations of iron, tungsten, and carbon, and of iron, nickel, and carbon: Proc. Inst. Mech. Eng., pt. 2, March-May, 1914, pp. 223-248.

[b] 0.15 or less.

[c] 0.02 or less.

[d] 0.04 or less.

[e] 0.01 or less.

[f] Tough means that the lathe chips curled off in spirals.

The strength and hardness of these steels may be greatly increased by heat treatment involving quenching and with only relatively small decrease in ductility.

THEORY OF TUNGSTEN STEEL.

Arnold and Read concluded that the carbon in the steels they examined was combined with iron when the tungsten was low, but that the higher the tungsten the more of the carbon was combined with it until in steel containing 11.5 per cent of tungsten none of the carbon was combined with iron, but all of it with tungsten. With still higher tungsten content the excess of tungsten was combined with iron.

BIBLIOGRAPHY ON TUNGSTEN STEEL.

FORBES, DAVID. Quarterly report on the progress of the iron and steel industries in foreign countries. Jour. Iron and Steel Inst., vol. 2, 1872, pp. 255–294. Gives chemical analysis of Mushet's "special steel" or tungsten steel.

HADFIELD, R. A. Alloys of iron and tungsten. Jour. Iron and Steel Inst., 1903, pt. 2, pp. 14–118. Presents bibliography of tungsten and tungsten steels dating from 1590.

GUILLET, LÉON. Aciers au tungstène. Rev. mét., vol. 1, 1904, pp. 263–283.

——— Constitution et propriétés des aciers au tungstène. Comp. rend., t. 139, Sept. 26, 1904, pp. 519–521.

——— Recherches sur les aciers au tungstène. Génie civil, t. 45, 1904, pp. 7, 27.

SWINDEN, THOMAS. Carbon-tungsten steels. Jour. Iron and Steel Inst., pt. 1, 1907, pp. 291–327.

——— The constitution of carbon-tungsten steels. Jour. Iron and Steel Inst., 1909, pt. 2, pp. 223–256.

MARS, G. Magnetstahl und permanenter Magnetismus. Stahl und Eisen, Bd. 29, 1909, pp. 1673, 1769.

ARNOLD, J. O., and READ, A. A. The chemical and mechanical relations of iron, tungsten, and carbon, and of iron, nickel, and carbon. Proc. Inst. Mech. Eng., March–May, 1914, pp. 223–279.

JARDINE, ROBERT. Valves of tungsten steel. Autocar, vol. 33, July 18, 1914, pp. 127–129.

SIMPLE CHROMIUM STEEL.

Simple chromium steels, though one of the earliest if not the first of the alloy steels to be made, are not now largely used though they are for quite a variety of purposes. In combination with other alloying elements, however, chromium is still one of the most important constituents of alloy steels.

The production of simple chromium steel ingots is thought to have been about 6,000 tons in 1913 with a content of chromium of 0.4 to 2 per cent. It is made by either the acid open hearth or crucible process. If made in crucibles the chromium in the form of ferrochromium is made a part of the original charge, but if made in the open-hearth furnace the ferrochromium is added just long enough

before casting for the alloy to be melted and well mixed with the charge.

The consumption of ferrochromium for steel making in this country in 1913 was between 3,000 and 4,000 tons, containing 60 to 70 per cent of chromium. If 1 per cent be assumed as the average content of chromium in the structural steels, and 4 per cent in the high-speed tool steels, a total of about 204,000 tons of steel of all kinds in the ladle contained chromium. The bulk of such steel was quaternary or complex steel, about 6,000 tons being considered as simple chromium steel, as already stated.

At steel-melting temperatures chromium has a greater affinity for oxygen than has iron, and therefore if any oxygen either free or in the form of oxide of iron comes in contact with melted steel that contains chromium, some of the chromium is wasted. It is not oxidized as rapidly as silicon and manganese, however, and therefore has little deoxidizing effect when added to an oxidized iron bath, the oxides and gases being controlled by other means.

The effect of a chromium content up to a maximum of 2½ per cent in steel is to increase the hardness moderately when the steel is in the natural state, as defined on page 6, and particularly when it is in the hardened condition after having been quenched.

METHODS OF WORKING.

Chromium steels are cast, forged, and rolled by the same plant and by the same methods as simple steels of the same or slightly higher carbon contents. Castings are annealed, or heat treated, as the conditions warrant or require to give the most suitable properties for the proposed use.

Chromium steels are perhaps never used in the untreated condition, and their properties in that state are therefore not given.

Composition and properties of heat-treated simple chromium steels.

Sample No.	Constituents.						Tensile strength.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	Ball hardness.	Heat treatment.	
	C	Mn	Si	S	P	Cr						Temperature at which steel was quenched in water.	Temperature at which hardness was drawn in air.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*		*°C.*	*°C.*
1.....	0.70	0.54	0.09	0.01	0.01	0.70	129,000	121,700	60	21	235	816	593
2.....	.70	.54	.09	.01	.01	.70	110,900	105,300	63	26	195	816	649
3.....	.70	.54	.09	.01	.01	.70	88,000	73,000	68	36	168	816	754
4.....	.40	.78	.54	.02	.01	.92	143,500	131,600	56	18	242	816	538
5.....	.40	.78	.54	.02	.01	.92	103,200	90,200	69	26	201	816	714
6.....	.91	.35	.08	.03	.01	.91	96,800	69,300	63	28	175	.....	.....

USES OF SIMPLE CHROMIUM STEELS.

The longest established use of chromium steels now current is in stamp shoes and dies for pulverizing certain gold and silver ores. These shoes and dies contain 0.8 to 0.9 per cent of carbon, with 0.4 to 0.5 per cent of chromium. They are preferably annealed to destroy ingotism and so impart some toughness to the metal, which increases their durability in an important degree.

Another long-established use of chromium steel is in 5-ply plates for the manufacture of safes for the safe-keeping of valuables. These plates are made of five alternate layers, two of chromium steel and three of soft steel or wrought iron, and after having been hardened offer great resistance to the drilling tools employed by burglars. The plates are, however, necessarily rather thin, usually between one-half and 1 inch thick, so that a safe wall or door to be more than an inch thick must be formed of two or more thicknesses, which are fastened together with screws. Many portable safes so made have been robbed by burglars who used liquid nitroglycerine, which was flowed into the joints and exploded, blowing out the door or wall. Such safes are therefore not made in such great numbers as formerly, but considerable quantities of chromium steel are used in large stationary safes, usually called vaults, where the individual pieces are larger and the other safeguards against burglary so effective that they are not attacked by burglars.

Hardened chromium-steel rolls having 0.9 per cent of carbon and 2 per cent of chromium are used for cold-rolling metals. They are glass hard so that the ball hardness can not be determined, the ball making no impression. The hardness, as determined by the sclerescope, is 107.

Files of chromium steel are excellent, and in 1913 about 3,000 tons of this steel went into them, the carbon content being 1.3 to 1.5 per cent and the chromium content about 0.5 per cent.

An important use of chromium steel is in balls and rollers for bearings. One large maker uses steel containing carbon, 1.10 per cent; chronium, 1.40 per cent; manganese, 0.35 per cent; sulphur, 0.025 per cent; and phosphorus, 0.025 per cent. Sizes smaller than one-half inch diameter are heat-treated by being quenched in water from 774° C. (1,425° F.) and then drawn to 190° C. (375° F.) for half an hour. For larger balls the quenching temperature is 802° C. (1,475° F.). The second heating does not produce an oxide color, but is enough to let down in some degree the internal stresses due to the irregular cooling of quenching so that the balls are less liable to crack spontaneously or to be broken in use.

The strength of a good, well-treated ball is prodigious, a ball three-fourths of an inch diameter, tested by the three-ball method,

sustaining a load of 52,000 pounds. On the small area of contact the intensity of the pressure amounts to over one million pounds per square inch.

The Society of Automobile Engineers recommends less chromium than that given above, or 1 to 1.2 per cent. A steel maker recommends 1.5 per cent.

A former important use of these steels was in armor-piercing projectiles. Cubillo [a] gives as the analysis of such a steel: C. 0.85 per cent, Mn. 0.38 per cent, Cr. 2.31 per cent, Si. 0.16 per cent, and P. 0.02 per cent. The physical properties were as follows:

Physical properties of certain armor-piercing steels.

Treatment.	Elastic limit.	Tensility.	Elongation in 2 inches.
	Pounds.	*Pounds.*	*Per cent.*
Annealed	47,700	102,000	20.5
Heat-treated	79,400	114,500	18.5

The greater part of projectiles, however, contain some nickel also, as noted in the discussion of nickel-chromium steels.

Chromium steels are preferred by some builders in certain automobile parts, though most makers of cars prefer nickel chromium.

BIBLIOGRAPHY ON CHROMIUM STEEL.

BRUSTLEIN, H. A. On chrome, pig iron, and steel. Jour. Iron and Steel Inst., 1886, pt. 2, pp. 770–778. Briefly describes experiments made by French railway companies.

HADFIELD, R. A. Alloys of iron and chromium, including a report by F. Osmond. Jour. Iron and Steel Inst., 1892, pt. 2, pp. 49–175. Includes discussion and bibliography.

GUILLET, LÉON. Les aciers au chrome. Rev. mét., t. 1, 1904, pp. 155–183.

——— Recherches sur les aciers au chrome. Génie civil, t. 44, 1904, pp. 281–298.

BRUSTLEIN, A. Comment l'acier chromé est devenu un produit industriel. Rev. mét., t. 2, 1905, pp. 508–515.

PERAR, U. C. Steel for cutters, punches, and dies. Am. Machinists, vol. 33, pt. 1, Jan 6, 1910, pp. 17–20.

ARNOLD, J. O., and READ, A. A. The chemical and mechanical relations of iron, chromium, and carbon. Jour. Iron and Steel Inst., 1911, pt. 1, pp. 249–268.

PORTEVIN, A. M. Sur les aciers au chrome. Rev. mét., vol. 8, 1911, pp. 802–803.

FRIEND, J. N. The corrodibility of nickel, chromium, and nickel chromium steels. Jour. Iron and Steel Inst., pt. 1, 1913, pp. 388–398. See also general bibliography.

MANGANESE STEEL.

Manganese steel in the commercial meaning of the name is a variety of iron containing 11 to 14 per cent of manganese and 1.0 to 1.3 per cent of carbon. The original patents covered alloys of iron with 7

[a] Cubillo, L., The manufacture of armor-piercing projectiles: Jour. Iron and Steel Inst., vol. 88, 1913, p. 251.

to 30 per cent of manganese but the steels within the limits of composition given have the greatest strength and ductility of any and are always meant when manganese steel is ordered without further qualification. Departure from these limits of analysis means in a general way that the steel is to that extent unsuited for the structural purposes for which manganese steel has been found applicable.

The bulk of the manganese steel made at present is put into castings, of which about 36,000 tons was made in 1913. The use of hot-worked (rolled or forged) manganese steel is now of importance, some 3,000 tons having been made in 1913, nearly all of which went into rails. These quantities call for about 60,000 tons of molten steel in the ladle.

Though about 40 concerns offer manganese-steel castings, only about half a dozen make any considerable quantity, having supplied practically all of that made in 1913.

MANUFACTURE.

Manganese steel is still made in the ladle according to Hadfield's expired patents by the mixture of decarburized iron and 80 per cent ferromanganese. The decarburized iron is prepared either by the pneumatic process, being blown in some one of the many modified pneumatic converters, or in the Siemens furnace. As ferromanganese forms such a large proportion of the charge, about one-seventh, it must be melted or nearly so before being added to or mixed with the decarburized iron, or the resulting steel would be too cold. The ferromanganese is usually melted in graphite crucibles or pots which is an expensive way but not yet generally superseded. The pots are heated in ordinary coal-fired melting holes. They usually may be used to melt eight or ten charges, whereas in steel melting they average less. This longer life when melting ferromanganese comes from both the lower melting temperature needed and the absence of solution of the graphite of the pot by the metal, common ferromanganese being saturated with carbon, whereas molten steel eagerly dissolves any carbon with which it comes in contact. The ferromanganese need not be completely melted, which of course would not be permissible with the steel.

The decarburized iron used should have a low carbon content, not over 0.10 per cent, so that the resulting steel may not have more than is desired. The proportion of carbon to manganese in the steel will, therefore, be a little more than in the ferromanganese.

After the manganese steel has been made in the ladle it should be cast as soon as practicable if it is to be used for castings, but if it is to be used for ingots a little time should be allowed for the silicate formed within the metal to collect and float to the top.

The quantity of manganese is proportioned to the size of the charge of decarburized iron with allowance for loss through oxidation of an amount equal to about 1½ per cent of the steel. Thus 14 per cent is added to yield 12.5 per cent in the steel. Everything is weighed—the stock before melting, the iron added to the vessel if decarburized by the pneumatic process, the molten ferromanganese, which is put in the ladle first, and the decarburized iron are all weighed, the weight of the decarburized iron giving the weight of the molten steel in the ladle. When the decarburized iron is prepared in a tilting Siemens furnace, a part may be taken out at a time and made into steel, the amount of iron being weighed by a suspended weighing machine on the crane.

Earnest efforts have been made to melt ferromanganese in a cupola because of the high cost of melting in pots, and some has been so melted in a commercial way. When the ferromanganese is melted in a cupola there is more loss of manganese, which offsets, in part at least, the lower cost of melting. The loss is diminished to a large extent by charging the ferromanganese in the center of the cupola with coke around the outside so that the metal is largely protected from free oxygen of the blast which would oxidize manganese if it came in contact with it. It is a matter for calculation which is to be chosen for any given conditions as being the cheaper or, all things considered, the most advantageous.

Another effect of the waste of manganese from the ferromanganese used in making manganese steel is that the carbon content is higher and perhaps undesirably so in the finished steel because of its concentration due to the waste of manganese. Carbon is not oxidized under usual conditions in fused ferromanganese because of the presence of the large excess of manganese which seizes any oxygen that reaches the alloy.

Manganese steel is usually made and handled in clay-lined ladles. Basic-lined ladles present some advantages, but clay is used because it is so much cheaper and more easily made into a lining. Such a lining is of course to be classed as acid, and sometimes strongly so, when quartz in the form of sand or ganister is mixed with the clay. Molten manganese steel in an acid-lined ladle continually makes a fusible and liquid slag, which is chiefly a silicate of manganese, green in color. It is formed of oxide of manganese, which is continually being oxidized by atmospheric oxygen, and the ladle lining. A little green silicate rises and joins the slag from within the metal, being formed from the silica contained in the decarburized iron and the oxide of manganese formed by substitution of manganese for iron in the oxide of iron in the metal. The thin fluid slag is troublesome, as it is not easily kept from entering the molds with the steel, where it is likely to cause a defect in the ingot or casting.

To avoid the trouble from the very liquid slag a "coffeepot" ladle is sometimes used, which is provided with a spout like that of a coffeepot, attached at one side and connecting with the ladle interior at the bottom. This arrangement acts effectively to skim the slag, which can not enter the spout until nearly all the steel has been poured out of the ladle.

The corrosion of the ladle lining is deepest at the slag line when the ladle is full, as the slag has more time to act on the lining at that level than at any other.

Because of its large content of carbon, silicon, and manganese, the latter fusing at 1,260° C., manganese steel melts at about 1,325° C., a temperature lower than that of simple steel, and one that favors the running of intricate castings. For the same reason manganese steel, containing so much gas solvent, is usually free from gas holes; but if the decarburized iron of which it is made is too hot, and therefore too heavily charged with gases, the solvent powers of the silicon and manganese may be exceeded, and the steel be saturated with gases, the ingots or castings being consequently infested with blowholes by the gases liberated in cooling.

COMPOSITION.

In making manganese steel one composition is practically standard. The usual analyses of manganese steel lie between the following limits: Carbon, 1.0 to 1.3 per cent; silicon, 0.3 to 0.8 per cent; manganese, 11.0 to 14.0 per cent; phosphorus, 0.05 to 0.08 per cent. The sulphur content is so low as to be negligible in manganese steel as in other iron-manganese alloys, from which any sulphur that may get in is quickly eliminated by the manganese, probably as sulphide, which rises to the surface or enters the slag. In the open the sulphur is burned by the oxygen of the air, forming sulphurous acid (SO_2), which may often be smelled coming from the molten steel.

Low-manganese steels with 7 to 8 per cent of manganese are finding some use, having a higher and better defined elastic limit than the regular grade and yet with considerable though much less ductility. They are also cheaper to make. They do not flow under impact as freely as the regular commercial grades, because, no doubt, of their martensitic structure.

Manganese-iron alloys containing 3 to 10 per cent of manganese and 1 per cent of carbon are martensitic. With the manganese over 10 per cent the structure is austenitic. The steels having 7 to 10 per cent of manganese are so different from commercial manganese steel that another name should be given them to avoid confusion. The name "loman steel," an abbreviation of "low-manganese steel," has been applied to them and seems to be suitable as a short distinctive name.

GENERAL PROPERTIES.

Manganese steel is a hard self-hardening steel, owing this property to its composition and not to treatment. It can not be softened by heating followed by slow cooling. It is, for a metal, a poor conductor of electricity.

Manganese steel has a high coefficient of expansion, small patterns being made with a shrinkage of five-sixteenths of an inch to 1 foot, which sometimes is not quite enough. A shrinkage of five-sixteenths of an inch to 1 foot gives a mean coefficient of expansion of about 0.000024 per degree centigrade.

In respect to specific gravity manganese steel is not to be distinguished from simple steels of the same carbon content, as all have, generally speaking, about the same.

Perhaps the most remarkable property of manganese steel is its almost total lack of magnetic permeability and susceptibility. This metal, containing 85 per cent of iron in a metallic form, is so slightly attracted by a magnet that the pull can not be felt with the hand, whereas magnetic oxide of iron, containing about 70 per cent of iron in a nonmetallic form, is strongly attracted. A magnetometer or even a pocket compass needle will usually detect magnetism in commercial manganese steel, especially if a test be made soon after the steel has been in contact with a magnet, but the amount that may be so detected is extremely small. For most practical purposes it is zero.

PROPERTIES OF MANGANESE STEEL IN THE RAW STATE.

The properties of manganese steel in the raw state are much like those of other raw high-carbon steels, the metal being very hard, but its ductility being practically negligible. The steel, because nonmagnetic, may be used for purposes requiring a hard nonmagnetic metal, if it is not liable to shock. With better tool steels, which may make machining manganese steel a commercial operation, the metal may find a field of use in electrical apparatus, replacing some brass or other nonferrous metals because of its lack of magnetic qualities and lower cost.

HEAT TREATMENT OF MANGANESE STEEL.

Although the composition of manganese steel is extremely important in determining its properties, the heat treatment to which it is subjected to develop in it its great toughness or ductility is even more so.

As used, it is almost universally water-toughened according to the method Hadfield set forth in his early papers [a] on the subject. This

[a] Hadfield, R. A., On manganese steel: Jour. Iron and Steel Inst., 1888, pt. 2, pp. 41–82; Manganese in its application to metallurgy: Proc. Inst. Civ. Eng., vol. 93, pt. 3, 1887–88, pp. 1–16; Some newly discovered properties of iron and manganese, loc. cit., pp. 61–126.

treatment consists in heating the whole article to about 1050° C. and then cooling it as quickly as possible by immersing it in cold water, the colder the water and the more of it, the better. It will not do to heat only a part of the piece for quenching, and if a part of a toughened article becomes heated to redness or near it by accident or design the whole piece should be reheated and again quenched to give it proper qualities for use.

No time should be lost in completing the heating and quenching after the piece has become red-hot to avoid oxidation as completely as possible. Manganese steel is a poor conductor of heat, a factor that interferes with its heat treatment and tends to limit the thickness of the steel that may be profitably treated. This limit of thickness is generally taken as 4 inches, though somewhat thicker pieces in which the presence of internal cracks in the central parts would not be ruinous are treated in particular instances.

A thick piece of manganese steel must be heated at a slow rate. The heating can not be properly done by placing the piece when cold in a hot furnace. The furnace if hot from previous use must be cooled down nearly to atmospheric temperature or to that of the piece to be toughened, if it is not cold, before it is placed in the heating chamber. If the furnace is much hotter than the piece the poor heat conductivity of the metal retards the passage of heat to the interior, and the temperature of the skin rises rapidly, because of which and because of the high coefficient of expansion of the metal the exterior is expanded so much sooner than the interior that the latter is likely to be torn apart, the cracks extending outward from the center toward the surface until the stresses are sufficiently relieved or they reach metal too much softened by the heat to crack.

Many have asked when first considering the question, "Why not quench the casting when still hot with the initial casting heat?" The answer is that the heat of the various parts of the piece is not sufficiently uniform, the thicker parts being hotter than the thinner. If the piece is what might be called of uniform thickness, any corners or edges or parts first laid bare after casting are cooler than the rest of the piece, and even if the piece be a sphere, which is almost the only shape that will show a surface of uniform temperature after casting, the interior will be so much hotter than the exterior, and will, therefore, when the sphere is immersed in a cooling bath, continue contracting so long after the surface is cold and contraction there has ceased that it will tear itself apart. The toughness of the metal will not prevent internal rupture under such conditions as there can be no contraction of area, as in the pulling test, to compensate for and so permit stretching of the metal, which must therefore separate at its weaker spots and be subject to cracks.

PROPERTIES OF HEAT-TREATED MANGANESE STEEL.

Hadfield's papers of 1888[a] gave the results of a large number of physical tests of manganese steels. These results indicate that the toughening effect of water quenching was imparted only when the steel contained at least 9 per cent of manganese. Since that date steels having as little as 7 per cent of manganese have been given a useful toughening effect though only a fraction of that of commercial manganese steel.

The hardness of toughened manganese steel is unique, and it may be termed a tough hardness and not a flinty hardness. Such steel may easily be dented with a hammer or marked with a file or chisel, but cutting it to a useful extent is almost impracticable, so that such finishing as is necessary is usually done by grinding with abrasive wheels.

The water toughening of manganese steel gives it great ductility—greater as to elongation, perhaps, than that of any other steel and exceeding sometimes 50 per cent in 8 inches, although its high degree of hardness is not greatly altered. This high ductility in combination with the great hardness of manganese steel gives it great resistance to abrasive wear as well as safety from breakage. Practically all manganese steel is used in the toughened state.

In the pulling test the percentage of contraction of area is less than the elongation, a result directly opposite to that with simple as well as most alloy steels, in which the percentage of contraction is usually twice or more that of the elongation. The pulled test piece has a rather uniform stretch throughout its length, whereas simple steels, as is well known, have a largely increased amount of stretch near the point of fracture. When a piece of manganese steel is pulled, the increase of strength due to cold working (stretching) is greater than the decrease in cross section due to contraction, so that a stretched part becomes stronger than the unstretched parts, and elongation then occurs at another place. As the pulling is continued, all parts of the pulled section stretch one after the other, with the result that when the piece is finally ruptured the stretch has been comparatively uniform. There is indeed an increased local extension and contraction close to the point of rupture, as with other ductile steels, but it is less marked in the manganese steels.

The elastic limit of manganese steel is unexpectedly low and not well defined, as the steel yields at a gradually increasing rate when pulled, as in testing, giving no point that, strictly speaking, can be said to be the elastic limit or even yield point. The strain diagram has no jog.

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[a] Hadfield, R. A., loc. cit.

A recent pulling test of forged, heat-treated, manganese steel gave the results following. The steel was cast in a test bar 3 inches square, forged down to a test piece of about the dimensions given, and finished by grinding.

Results of pulling test of piece of manganese steel.

Diameter of piece, inches	0.823
Length, inches	2
Tensile strength per square inch, pounds	152,840
Elastic limit per square inch, pounds	56,400
Elongation, per cent	51
Contraction, per cent	39.5
Carbon, per cent	1.10
Manganese, per cent	12.4
Silicon, per cent	0.15
Phosphorus, per cent	0.06

The length of the pulled section of a manganese-steel test piece does not affect the elongation as much as is the case with simple steels because the stretch is so much more nearly uniform, as described above.

Owing to its lack of elastic limit and to its high ductility, manganese steel is prone to flow under stress, and it does not have high resistance to compression or to continually repeated blows of a hard mineral or other material that will gradually batter it out of shape. The results of tests of this property made with the Government testing machine at the Watertown Arsenal were as follows:

Results of compression tests of cast manganese steel.

No. of test piece.	Analysis.				Permanent set at a pressure per square inch of—				Total load.
	C.	Si.	Mn.	Cr.	40,000 pounds.	50,000 pounds.	60,000 pounds.	70,000 pounds.	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Pounds.*
1	1.23	0.95	12.6	.....	0.0006	0.0036	0.0213	0.0981	190,100
2	1.26	.54	12.8	.....	.0020	.0046	.0182	.0899	180,100
3	1.31	.43	12.7	.....	.0010	.0036	.0204	.0998	172,300
4	1.22	.72	11.7	0.86	.0002	.0009	.0038	.0220	175,200

All test pieces were cast and finished by grinding to 4 inches long and 1.129 inches in diameter, giving 1 square inch of cross-sectional area. At the total load the pieces buckled. The permanent set at a pressure of 40,000 pounds per square inch shows that the limit of elasticity was passed in every case.

The hardness by Brinell's ball test of manganese steel is low, running usually about 190.

The merit number obtained by multiplying the figure representing the tensile strength of a material by the figure representing its

elongation gives roughly a fair idea of the amount of work that must be expended upon the material to break it—that is, its strength must be overcome through a distance represented by its ductility before it will be broken. The merit number of manganese steel is perhaps the greatest of all known steels. The merit numbers of various metals are given below.

Merit numbers of various metals.

Metal.	Tensile strength.	Elongation.	Merit number.
	Pounds.	*Per cent.*	
Manganese steel	140,000	50	7,000,000
Soft steel	60,000	30	1,800,000
Tool steel	130,000	5	650,000
Cast iron	20,000	.5	10,000
Nickel steel, natural	95,000	21	1,995,000
Nickel steel, heat-treated	207,000	14	2,898,000

Of course, each of these metals yields to stress within its elastic limit, so that some work must be expended on it to strain it up to that point. With a nonductile metal, such as cast iron or even raw manganese steel, this is the reason for such small resistance to shock as it has. The elongation of 0.5 per cent given in the table is high for cast iron, but its power to absorb energy without breaking is increased by its ability to be strained within the elastic limit. If a material were to have no ductility and were perfectly rigid, the slightest blow would break it. Glass, having no ductility and being nearly rigid, comes near to being such a material. Of course, it may be easily broken by a blow, though it offers considerable resistance to a static load—enough to be useful, as in a floor plate, for example.

The effect of the toughening operation on the merit number of manganese steel is shown by the following results, taken from Hadfield's first paper.[a]

Results of tests of toughening operation on merit number of manganese steel.

Sample No.	Condition.	Tensile strength.	Elongation.	Merit number.
		Pounds.	*Per cent.*	
1	As forged	88,120	3.5	308,420
	Toughened	145,240	50.0	[a] 7,262,000
2	As forged	81,600	1.56	127,296
	Toughened	150,370	44.44	[b] 6,682,440

[a] The toughened steel was 24 times as hard to break as the untoughened.
[b] The toughened steel was 50 times as hard to break as the untoughened.

MANGANESE-STEEL CASTINGS.

Manganese-steel castings are made in dry sand, in green sand, and in some instances in iron molds, the considerations leading to the adoption of any particular material being much the same as with

[a] Hadfield, R. A., Manganese in iron and steel: Proc. Inst. Civ. Eng., vol. 93, pt. 3, 1887-88, pp. 1-16.

ordinary simple steel castings, such as danger of pulling apart or cracking in cooling, misrunning, or failure to fill the mold properly, and breaking or washing of the mold, and numerous others. The high coefficient of expansion of manganese steel must be considered, as it increases the liability of a casting to be cracked or pulled apart by shrinkage in cooling.

Manganese steel is prone to settle as it solidifies, demanding, for a given massiveness of design, larger sink heads than simple steels to feed the casting properly and prevent settle holes.

Even more than with other steel castings it is important that manganese-steel castings be so designed that the mass is fairly uniform throughout, or in particular that no part is much thicker than the rest. If a thick part is unavoidable, it should be connected with a sink head by metal as thick or nearly so. Thus, bosses and heavy fillets, often advisable in iron and simple steel castings, should be avoided because of the local increase of the mass they cause. The trouble is that a heavy part incompletely fed will be unsound in its central parts. A hole or recess cored in, if permissible, may prevent the central cavity, or an iron or soft steel core may be imbedded in the thick part, which, by hastening the solidification of the metal, may prevent the formation of holes or loose metal there.

USES OF MANGANESE STEEL.

The specific uses for which manganese steel is employed may be learned from the catalogues of the producers. It is used in equipment employed in the mining, milling, and treatment of ores and other mineral products, quarrying and rock-dressing, digging and dredging, railway tracks, parts of machines exposed to gritty wear, and burglar-proof safes and vaults for the safe-keeping of money and valuables.

Because of its low-yield point manganese steel does not give satisfaction in many lines for which otherwise it seems to be eminently fitted.

When the service required is such that the resistance of the metal to flow is not exceeded, the results are often excellent. When for any reason the pressure at the point of wear passes the flowing point the results are disappointing, though even then they may be better than those obtained by the use of any other material.

In applying manganese steel to a new use determination of its fitness is nearly always a matter to be demonstrated, though this is less general than formerly as knowledge and experience have increased. Some of the fields that it was thought at first would be well occupied by manganese steel it has never won; others that were formerly unthought of it has found easy of conquest. Much uncertainty has come in applying it to new uses by the requirement that

manganese steel as a metal be substituted for some other metal of a certain size and shape. The results are often not fully foreseen and liable to be unsatisfactory as such a substitution is itself unscientific. The proper way to apply a new metal of unique properties to a new use is to study the service to be rendered and then to devise methods of doing the work and to design parts therefor such as will utilize to the best advantage the superior properties of the new metal. Sometimes however this is not easily done. Nevertheless manganese steel, because of its properties, presents difficulties that are usually best overcome by such a plan if the highest benefit attainable from its use is to be gained.

It is a well-established rule that manganese steel resists admirably abrasion under slow speeds of impact as in Blake crushers, rolls, gyratory crushers, and similar machines but results in high-speed grinders, such as the various centrifugal mills, are, if not poor, at least such as will not often warrant the expense of manganese-steel wearing parts, especially if such parts require some finishing, which must be done by slow and expensive grinding. In accordance with the same rules manganese steel makes good car wheels that are to run at slow speeds such as on mine cars, but it is unsatisfactory in wheels used on railway cars that are run at high speeds.

For railway-track work manganese-steel cast frogs, switches, curved rails, and other special work are most excellent and they are extensively used.

The properties of the metal were early seen to make it an ideal material of which to make burglar-proof safes and vaults; that is, it is too hard to be cut, and too strong to be broken even by considerable charges of dynamite and nitroglycerin. It has now been employed for this purpose some 15 years and no genuine manganese-steel safe has yet been opened by burglars though a few have been attacked. Burglars have learned the futility of their efforts to rob such a safe.

The nonmagnetic property of manganese steel has found an important use in the cover plates of lifting magnets for handling heavy iron and steel articles where it is subjected to hard blows from the pieces jumping to meet the magnets. It offers little or no obstruction to the passage of the magnetic attraction. It is also used in the structure about the compasses on some ships because it does not affect the compass needle. This use may become important.

On the magnetic survey yacht *Carnegie* of the Carnegie Institution, which is built wholly of wood, bronze, and other nonmagnetic materials, manganese steel, because of its nonmagnetic property, is used in the grate and other parts of the gas producer which were necessarily made of steel.

HOT-WORKED MANGANESE STEEL.

Manganese steel is, like simple steel, or even more so, improved in its physical properties by hot working (forging or rolling). Cast test pieces usually give misleading results because of imperfections due to casting. To cut out of the solid and finish by grinding a test piece of cast manganese steel is expensive, and when done the piece is liable to be so imperfect as to give practically valueless information. In this respect, however, it is like many other cast metals.

A steel that cast and heat-treated may show a tensile strength of 80,000 pounds per square inch with 20 per cent elongation may have, when well worked by forging and rolling and then heat-treated, a tensile strength of 140,000 pounds per square inch and 50 per cent of elongation in 8 inches.

The first commercial use of manganese steel was in dredge pins for chain bucket dredges, which were forged from square ingots in 1889 or 1890 by Hadfield at Sheffield. The greater ease of casting the metal, however, led to the employment of castings wherever they could be used. The records made by castings have stimulated in recent years the production of rolled pieces, particularly rails, plates for chute linings, and screens for crushed stone. A beginning has been made in the use of forged manganese steel for purposes for which its great strength and ductility (its merit number) and the consequent margin of safety it affords make it particularly reliable. Its use in spring hangers on locomotives is an example. Cold working such as stretching or cold rolling rapidly raises its tensile strength and elastic limit but destroys most of its ductility. Cold-rolled manganese steel on test has shown a tensile strength of 250,000 pounds per square inch and an elastic limit of 230,000 pounds.

For screening coke woven screens of manganese-steel bars are giving a promise of life a hundred times as great as that of screens made of the soft simple steel usually used for this purpose. Coke rapidly wears away metal on which it impinges, as though it were composed of or contained many minute diamonds.

The high electrical resistance of manganese steel would no doubt lead to its general use as a resistance material in the form of wire, for which it has been tried, were it not that its hardness makes drawing it into wire too costly an operation. Its electrical properties are good for this purpose, its specific resistance running from 65 to 75 microhms per cubic centimeter.

Agricultural implements made largely of rolled plates, such as shovels and hoes, offer a most inviting field for the use of manganese steel, especially for kinds of service in which the plates are used

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up by wear. If the service is such that they rust or corrode much more than they wear, tools made of simple steel may be as good. This field is now being entered.

The largest demand for hot-worked manganese steel is in rails for railroads. The rails are rolled on ordinary rail mills and are heat-treated by being quenched immediately after rolling. The service rendered by the rails is excellent and their use is extending. Some railroad men think their durability at least five times that of ordinary rails. Their value to the railroads is not, however, as great as their service compared with that of simple steel rails as the interest on the extra price and the relatively small value of the scrap when they are worn out tell against them, though the saving in the cost of laying is in their favor.

Perforated plates of manganese steel for screening ores, crushed stone, and other mineral products are promised, but special punching machinery is needed to punch the holes, as the holes probably must be punched at a much slower speed than that at which simple steels are punched.

CONCLUSIONS.

The economies resulting from the use of manganese steel in its various fields of service have been great. Perhaps the most conspicuous example of its use was in connection with the Panama Canal where years of time and millions of expense were saved by its use.

The promise of usefulness because of its great tensile strength and more remarkable ductility, there is ground to hope, may in the near future be fulfilled.

BIBLIOGRAPHY ON MANGANESE STEEL.

HADFIELD, R. A. On manganese steel. Jour., Iron and Steel Inst., 1888, pt. 2, pp. 41–82.

——— Manganese in its application to metallurgy. Proc. Inst. Civ. Eng., vol. 93, pt. 3, 1887–88, pp. 1–60. Some newly discovered properties of iron and manganese, pp.61–126.

——— Iron alloys with special reference to manganese steel. Proc. Am. Inst. Min. Eng., vol. 23, 1893, pp. 159–196.

MUKAI, TETSKICHI. Studien über chemisch-analytische und mikroscopische Untersuchung des Manganstahls. Friedberg, 1892.

HOWE, H. M. Note on manganese steel. Proc. Am. Inst. Min. Eng., vol. 21, 1892, pp. 625–631.

——— Manganese steel. Trans. Am. Soc. Mech. Eng., vol. 12, 1891, pp. 955–974.

——— The heat treatment of steel. Proc. Am. Inst. Min. Eng., vol. 23, 1893, pp. 467–476.

LEDEBUR, A. Ueber Manganstahl. Stahl und Eisen, Jahrg. 13, June, 1893, pp. 504–507.

HADFIELD, R. A. The results of heat treatment on manganese steel and their bearing upon carbon steel. Jour. Iron and Steel Inst., 1894, pt. 1, pp. 156–251.

GUILLET, LÉON. Aciers au manganèse. Soc. d'encourage. l'ind. nat., t. 102, 1903, pp. 421–448.

——— Recherches sur les aciers au manganèse. Génie civil, t. 43, 1903, pp. 261, 280.

——— Nouvelles recherches sur les aciers au manganèse. Rev. mét., t. 1, 1904, pp. 89–91.

LEDEBUR, A. L. Guillet's Untersuchungen über Manganstahl. Stahl und Eisen, Jahrg. 24, March 1, 1904, pp. 281–285.

ARNOLD, J. O., and KNOWLES, F. K. Preliminary note on the influence of manganese on iron. Jour. Iron and Steel Inst., 1906, pt. 1, pp. 106–124.

LAKE, E. F. Manganese steel and some of its uses. Am. Machinist, vol. 30, pt. 1, May 16, 1907, pp. 700–702.

GÉNIE CIVIL. L'acier au manganèse. T. 52, 1908, pp. 288–290.

RAILROAD GAZETTE. Rolled manganese steel rail. Vol. 45, December 11, 1908, pp. 1536–1538.

IRON AGE. Manganese-steel rails rolled at the Passaic works. Vol. 82, September 10, 1908, p. 709.

REVUE DE MÉTALLURGIE. L'acier au manganèse. Vol. 6, May, 1909, pp. 551–561. Letter from Schneider & Co., in reply to note in the Iron Age of September 10, 1908.

BURGESS, C. F., and ASTON, JAMES. Observations upon the alloys of iron and manganese. Electrochem. and Met. Ind., vol. 7, November, 1909, pp. 476–478.

COE, H. I. Manganese and its effect on iron and steel. Proc. Staffordshire Iron and Steel Inst., vol. 25, pp. 16–47. Includes discussion and bibliography.

AMERICAN MACHINIST. A machine shop without cutting tools. Vol. 32, pt. 2, Nov. 25, 1909, pp. 893–897.

IRON AGE. Manganese-steel products. Vol. 84, Sept. 30, 1909, pp. 984–987.

POTTER, W. S. Manganese steel. Jour. West. Soc. Eng., vol. 14, 1909, pp. 212–240.

IRON AGE. Rolled manganese steel rails. Vol. 83, April 22, 1909, pp. 1261–1262.

STRONG, J. B. Rolled manganese-steel rails. Ry. and Eng. Rev., vol. 49, March 13, 1909, pp. 214–215.

ARNOLD, J. O. and READ, A. A. The chemical and mechanical relations of iron, manganese, and carbon. Jour. Iron and Steel Inst., 1910, pt. 1, pp. 169–184.

JOHNSON, F. E. Manganese steel. Jour. Assn. Eng. Soc., vol. 45, November, 1910, pp. 175–183.

LAKE, E. F. The various effects of manganese in steel. Am. Machinist, vol. 33, pt. 1, March 10, 1910, pp. 456–457.

SPRINGER, J. F. Manganese steel. Cassier's Mag., vol. 39, December, 1910, pp. 99–116.

KNEISLY, G. W. The history and manufacture of manganese steel. Central and Eng. News, vol. 23, 1911, pp. 252–254.

HILPERT, S., and MATHESIUS, W. The magnetic properties of manganese and nickel steels. Jour. Iron and Steel Inst, 1912, pt. 2, pp. 302–310. Extract of a report published in Stahl und Eisen, 1912, p. 96, and also of the thesis of W. Mathesius, Berlin, 1912. Technische Hochschule.

FOUNDRY. Making manganese steel castings machineable. Vol. 40, July, 1912, p. 271. Describes method patented by F. Kohlhaas, Düsseldorf, Germany.

HADFIELD, R. A. Heating and cooling curves of manganese steel. Jour. Iron and Steel Inst., pt. 2, 1913, pp. 191–202.

HALL, J. H. Manganese-steel castings. Iron Age, vol. 91, March 20, 1913, pp. 712–713. Describes practice of the Taylor-Wharton Iron & Steel Co.

RAILWAY AND ENGINEERING REVIEW. New track appliances; manganese steel. Vol. 53, Oct. 11, 1913, pp. 955–956. From report to the Roadmasters' and Maintenance of Way Association, Chicago, September 11, 1913.

IRON TRADE REVIEW. Practice of the Edgar Allen American Manganese Steel Co. Vol. 52, June 19, 1913, pp. 1404–1411.

STONE, S. R. Manganese steel for machinery parts. Iron Age, vol. 91, Jan. 9, 1913, pp. 140–142.

ELECTRIC RAILWAY JOURNAL. Chicago's experience with solid and insert manganese special track work. Vol. 43, May 30, 1914, pp. 1221–1222.

HADFIELD, R. A., and HOPKINSON, B. The magnetic and mechanical properties of manganese steel. Jour. Iron and Steel Inst., pt. 1, 1914, pp. 106–137.

HADFIELD, R. A. Manganese-steel rails. Bull. Am. Inst. Min. Eng., February, 1914, pp. 259–265.

HOPKINSON, B., and HADFIELD, R. A. Research with regard to the nonmagnetic and magnetic conditions of manganese steel. Bull. Am. Inst. Min. Eng., March, 1914, pp. 513–530.

POTTER, W. S. Manganese steel, with especial reference to the relation of physical properties to microstructure and critical ranges. Bull. Am. Inst. Min. Eng., April, 1914, pp. 601–634.

ZERHANSEN, F. R. How manganese-steel castings are made; details of molding, melting, and pattern making. Foundry, vol. 42, April, 1914, p. 132.

SIMPLE NICKEL STEELS.

Nickel steel was chronologically the fourth alloy steel to be introduced, it having been in use for 25 years, and the steels to which nickel is added aggregate a large tonnage. In 1913, including the nickel-chromium steels as well as the simple nickel steels, the total amount of steel produced to which nickel was added was about 150,000 tons in the ladle, of which about 50,000 tons was simple nickel steel. The field for the latter is being steadily narrowed by the substitution of the cheaper or better nickel-chromium steels.

The useful nickel-iron alloys range, with large intervals, from 2 to 46 per cent of nickel, a greater compass than is covered by any other element alloyed with iron. The addition of less than 2 per cent of nickel alone does not seem to give enough benefit to make the addition worth while.

Nickel in untreated ordinary nickel steel raises the tensile strength, and in a greater proportion the elastic limit for a given content of carbon without decreasing the ductility.

Nickel steels with the different percentages of nickel present about the same range of internal microscopic structures as do manganese-iron alloys. With low-nickel content, as in the great bulk of nickel steels made, the unhardened steel is pearlitic. Higher nickel content gives martensitic structure and still higher austenitic. Certain steels with each of these structures find uses as is noted in subsequent pages.

MANUFACTURE OF SIMPLE NICKEL STEEL.

Nickel steel is made by any of the steel-making processes but most of it is produced in the open-hearth furnace. The operations are similar to those followed in the production of simple steels,

the nickel being either in the materials of the original charge or added in the metallic form at any time long enough before the heat is cast for the nickel to be melted and thoroughly mixed with the metal of the charge. Nickel is negative to iron at steel-melting temperatures and the iron protects it from oxidation and even reduces it from its oxide so that it is not wasted to any considerable extent in melting or working even when iron ore is added to the bath. On the other hand it does not deoxidize the metal or decompose carbonic oxide or keep the hydrogen and other gases in solution. It is not added, therefore, for curative purposes as it gives no aid in rendering steel sound, or free from holes. In fact, nickel steel is prone to have seams and surface defects after it has been rolled, which is one reason against its wider use. The service of nickel is merely as an alloying element, to improve the physical properties of the finished steel either in its natural or heat-treated condition.

As might be expected from an alloying metal whose atomic weight, specific gravity, and fusion point are so near those of iron, nickel does not segregate much as the steel solidifies, and is claimed to hinder in some degree the segregation of carbon and the other less metallic ingredients. A reasonable explanation of this action of nickel on the other elements has not yet been established.

WORKING OF SIMPLE NICKEL STEEL.

Ordinary simple nickel steel (3 to 4 per cent nickel) is worked hot by the usual forging and rolling operations much as simple steel is worked. The higher nickel steels are more difficult to work, having narrower ranges of temperature at which they may be hot-worked without showing signs of redshortness. In the ordinary grades seams and adhering scale give some trouble.

Although molten iron protects molten nickel from oxidation, as stated, iron can not protect nickel from oxidation in scale formed on nickel steel, as in the heating furnace. The scale formed sticks much more firmly to the metal than that of simple steel both hot and cold and requires particular measures for its removal. Articles such as plates, having large flat surfaces from which the scale can not escape even if loosened by such means as rolls or the flat dies of the forging press, are sometimes cleaned cold by electrically driven machines which break up the scale by a shower of blows with chisels or hammers. A round article is much more satisfactorily cleaned of scale by the forging operation, as the metal is worked while not in contact with the dies, and the scale is thereby loosened and falls off. The scale naturally escapes more easily from the under side of a rolled plate than from the top in rolling, and some mills are

equipped with apparatus for turning the plate bottom up before it is finished, so that the scale which has been repeatedly loosened and then rolled in again by the rolls can drop off when loosened from the under side.

Steels containing useful quantities of nickel are liable to contain seams that appear as dark-colored lines in the metal. The seams doubtless come, sometimes at least, from "skin" gas holes which become oxidized on their walls, and, although such oxidized holes will, if present, forms seams in any steel, they seem to persist more in nickel steel because, perhaps, the nickel prevents the welding of such holes, as may happen with holes in simple steels if they are squeezed together while hot enough and the walls are clean and not oxidized. A hole near the surface in nickel steel might conceivably, therefore, be drawn out and the slit formed be opened to the air by the hot working, then oxidized on its inner surface, and form a seam, when a similar hole in simple steel would be welded and therefore not form a seam. Nickel-steel ingots should therefore be made sound and free from gas holes. It is held by some persons that seams develop in rolling without being caused by gas holes, and that this tendency is lessened by rolling at a high temperature, about 1,300° C. (2,372° F.).

GENERAL CHARACTER OF NICKEL STEEL USED FOR STRUCTURAL PURPOSES.

The great bulk of simple nickel steels contain from 2 to 4 per cent of nickel, a proportion that affords the most suitable physical properties for nearly all structural purposes, and the nickel content usually aimed at in steels for structural purposes is 3.25 per cent. This grade might be called ordinary nickel steel as it is usually meant when nickel steel is mentioned without further specification. It has high value for structural purposes such as bridges, gun forgings, machine parts, engine and automobile parts, and any similar line of service that is too severe for simple steels.

The bridges in which it is used are particularly those of great span, and it is nearly always used in the natural or annealed condition when the additional strength and ductility imported is that due to the mere presence of nickel in the metal. Important quantities are used in the Queensboro, Manhattan, St. Louis Municipal, and Quebec bridges, and the Kansas City viaduct. Some nickel-steel tension bridge members have been heat treated by heating and quenching, being immersed in water edgewise with the longitudinal axis horizontal, and afterward drawn back by a second heating to give an elastic limit of 55,000 pounds per square inch, a rather low figure. A relatively low percentage of nickel, or about 2 per cent, is sufficient afford steel with such a property, when heat treated.

The use of nickel steel in bridges saves some weight, a detail of importance in such bridges as those mentioned, but when the span is moderate a bridge of simple steel is perhaps as good and is less costly even though it contains considerably more weight of metal.

Steel with 2 per cent of nickel is used in seamless tubes such as are used for bicycles and for other equipment requiring a high-grade tube. They are not heat treated, but higher properties than those of the steel in its natural state are imparted by the cold-drawing operations by which these tubes are finished. The ordinary grade with 3.5 per cent nickel is used in cannon, being always heat treated for this use. It is also used in many automobile parts, the variety of high properties obtainable in it by modifying its heat treatment rendering it fit for almost any service demanding a strength and security from breakage that a simple steel will not meet.

In some large dynamos the revolving fields are connected by nickel-steel rings having 3 per cent nickel, the metal being particularly well suited for the purpose both by its strength and its magnetic efficiency, the permeability being high and the hysteresis losses low.

CHARACTERISTICS OF DIFFERENT NICKEL STEELS USED IN RAILS.

Nickel-steel rails usually having about 3.5 per cent of nickel have been tried by many railroads and are generally considered unsatisfactory though small lots are still being made chiefly for use in tunnels and other unusually wet or damp places, both for their ability to resist rusting and for safety from breakage. Their price is nearly twice that of simple steel rails and they sometimes give three times the service but their average life has been much less than that. One lot of Bessemer nickel-steel rails which gave between one to two times the service of simple Bessemer steel rails wore unevenly and the metal flowed over the side of the head on the curve so that it was finally detached in thin splinters, some of which were 3 or 4 feet long. The rails from the upper parts of the ingots were more unsatisfactory than those from the bottom and though the ingots were not examined for their soundness it seems evident that their upper parts were infested with blowholes as well as pipe, and that none of the holes or pipe were welded up in rolling, as the effect of nickel in hindering welding of steel is well established.

PROPERTIES OF ORDINARY NICKEL STEEL.

The properties of ordinary nickel steel are given below. All the samples consisted of small test pieces, and elongations were measured on 2 inches except as noted.

Properties of ordinary nickel steels.

Sample No.	Composition.						Condition.	Physical properties.				
	C.	Mn.	Si.	S.	P.	Ni.		Tensile strength.	Elastic limit.	Elongation.	Contraction.	Ball hardness.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*	
1[a]	0.28	0.57	.....	0.03	0.02	3.44	Natural state.....	95,420	56,670	[b] 21.2	50	.....
2[c]	.40	.64	.....	.02	.01	3.43	Annealed.....	98,800	51,400	[d] 12.4	33	.....
3[c]	.40	.55	.....	.03	.01	3.70	.....do.....	93,180	56,060	[d] 15.8	40	.....
4[e]	.20	.65	.....	.04	.04	3.5	.....do.....	.....	43,000	27	62	170
5[e]	.20	.65	.....	.04	.04	3.5	(*f*).....	.....	95,000	20	72	216
6[e]	.20	.65	.....	.04	.04	3.5	(*g*).....	.....	140,000	14	61	330
7[e]	.30	.65	.....	.04	.04	3.5	Annealed.....	.....	63.000	27	63	163
8[e]	.30	.65	.....	.04	.04	3.5	(*h*).....	.....	87,000	25	68	207
9[e]	.30	.65	.....	.04	.04	3.5	(*i*).....	.....	123,000	15	57	269
10[e]	.30	.65	.....	.04	.04	3.5	(*j*).....	.....	187,000	13	57	405
11[k]	.25	.74	0.21	.01	.01	3.55	(*l*).....	207,000	177,000	14	60	395
12[k]	.25	.74	.21	.01	.01	3.55	(*m*).....	135,000	117,000	20	67	267

[a] Sample represented untreated steel for Quebec bridge.
[b] In 8 inches.
[c] Full size eyebars for St. Louis Municipal Bridge.
[d] In 18 feet.
[e] Figures taken from Fourth report of Iron and Steel Division: Bull. Soc. Automobile Eng., vol. 4, 1913, p. 168.
[f] Quenched in water at 850° C.; hardness drawn in air at 538° C.
[g] Quenched in water at 800° C.; hardness drawn in air at 316° C.
[h] Quenched in water at 800° C.; hardness drawn in air at 593° C.
[i] Quenched in water at 800° C.; hardness drawn in air at 399° C.
[j] Quenched in water at 800° C.; hardness drawn in air at 316° C.
[k] Figures furnished by Halcomb Steel Co.
[l] Quenched in water at 843° C.; hardness drawn in air at 316° C.
[m] Quenched in water at 843° C.; hardness drawn in air at 538° C.

One per cent of nickel in ordinary nickel steel in the natural state raises the tensility about 6,000 to 8,000 pounds per square inch.

The table shows that ordinary nickel steels may be so made as to have a wide range of properties that make them suitable for any structural purposes for which they are not too expensive.

The properties of one grade of nickel-steel castings made for special purposes are as follows: Composition, C 0.20 per cent, Mn 0.50 per cent, Si 0.35 per cent, Ni 2.50 per cent; tensile strength, 85,000 pounds per square inch; elongation, 25 per cent; contraction, 40 per cent. This steel was not given treatment involving quenching but was merely annealed.

Steel containing 5 to 8 per cent of nickel presents a sort of critical point, that proportion being the lowest at which, with the usual range of carbon, the structure is all martensitic and consequently very hard, the martensitic state being equivalent to the hardened state of simple steels. Such steel is difficult to work hot or cold but can be rolled if proper care is used. It finds some usefulness in places where great resistance to shock is required, particularly in thin shield plates about 0.15 inch thick which are used on one side of the caisson of field artillery to protect the ammunition, and the men who serve it, from rifle fire. A sample analyzed for "Tests of Metals" [a] gave the follow-

[a] Report of the tests of metals and other materials for industrial purposes, 1907, War Department, 1908, p. 42.

ing composition in percentages: C 0.42, Mn 0.49, Si 0.26, S 0.02, P 0.02, Ni 6.68.

The content of carbon determines the minimum amount of nickel which must be present to make the steel wholly martensitic. Thus if the carbon content is low, about 0.20 per cent, 8 per cent of nickel is required, whereas if the carbon content is about 0.80 per cent the steel is martensitic when there is 5 per cent of nickel contained. The analysis given last above represents martensitic steel.

Guillet [a] gives the properties of a similar steel, with 6 per cent of nickel and 0.38 per cent carbon, as follows:

Properties of nickel steel containing 6 per cent of nickel.

Condition.	C.	Ni.	Tensile strength.	Elastic limit.	Elongation.	Contraction.	Shock.
	Per ct.	*Per ct.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	
Annealed	0.38	6.0	113,760	99,540	20	65	30
Air hardened at 850° C	.....	.....	177,750	156,420	11	53	19
Quenched in water	.....	.....	199,080	177,750	10	50	17

He does not say whether this steel was martensitic, but the high elastic limits indicate that it was probably largely so, even in the annealed condition.

Steel with 8 per cent nickel has one transformation point at 510° C. (950° F.) where points Ar_1, Ar_2, and Ar_3 are all merged into one. Eight per cent is the highest useful content of nickel in nickel steel that is amenable to ordinary annealing and quenching operations. Hardening by quenching does not occur in steels containing 10 per cent or more of nickel which are on the contrary softened by heating and quenching.

NICKEL-IRON ALLOY DISCOVERED BY ARNOLD AND READ.

The 13 per cent nickel-iron alloy with 0.55 per cent carbon discovered recently by Arnold and Read [b] is noteworthy as it seems to possess the highest strength of any of the nickel steels. It is so hard as to be unmachinable and the investigators mentioned were not able to drill it even to get some drillings for analysis, the composition mentioned being what they aimed at when making the steel. It has a yield point of about 134,000 pounds per square inch, a tensile strength of about 195,000 pounds, with 12 per cent of elongation in 2 inches. This gives a merit figure of about 2,300,000 which is very high for such a hard steel though it does not compare with the 7,000,000

[a] Guillet, Léon, Nouveaux essais au choc a témperatures variables: Rev. mét., t. 7, October, 1910, pp. 837-844.

[b] Arnold, J. O., and Read, A. A., The chemical and mechanical relations of iron, tungsten, and carbon, and of nickel, iron, and carbon: Proc. Inst. Mech. Eng., March-May, 1914, pp. 223-279.

of forged manganese steel. Steel of this composition might have been expected to show maximum strength as a result of Hadfield's experiments,[a] though he did not include this grade in his series of samples. He found that low-carbon steels with 11.4 and 15.5 per cent of nickel each had a tensility of 210,560 pounds, which was more than was possessed by the steels next above and below. The curve therefore should have reached a maximum between them with a nickel content of about 13.5 per cent.

Arnold and Read's steel should, of course, have a higher tensility, or about 215,000 pounds, to harmonize with Hadfield's, and further tests are needed to establish the exact path of the curve. Arnold and Read note that the composition of this steel nearly corresponds with the formula Fe_7Ni. With such properties as it possesses this steel is likely to find at least a limited field of usefulness.

PROPERTIES OF DIFFERENT STEELS HAVING DIFFERENT PERCENTAGES OF NICKEL.

Before Arnold and Read's discovery of the 13 per cent grade, 15 per cent nickel steel was thought to have the greatest strength of all the nickel steels—that is, in the natural state. This variety has been employed in a few instances for shafting and similar service for which other steels failed, but the amount of it used is negligible in statistics. It is hard to machine, and heating followed by slow cooling does not soften it, though heating and quenching does enough to allow it to be machined slowly. It has a tensility of about 170,000 pounds and an elastic limit of 150,000 pounds per square inch, according to one observer, though, as stated above, Hadfield obtained 210,560 pounds tensility, with little ductility. It is likely that the properties desired when this steel was used, particularly its ductility, could now be surpassed by the much cheaper heat-treated ordinary nickel or nickel-chromium steels.

Eighteen per cent nickel-iron alloy, although not useful, is worthy of note here because of its anomalous action (according to Sexton and Primrose[b]) when cooled from 200° C. (392° F.). At first it contracts uniformly until its temperature falls to 130° C. (266° F.). Then it expands while cooling to 60° C. (140° F.), when it again contracts as the temperature falls farther.

Twenty-two per cent nickel steel is used when resistance to rusting or corrosion is desired. A noted example is the valve stems of the salt-water fire-protection service of the city of New York where the apparatus may not be allowed to become inoperative or hard of action from the formation of rust. It is also used sometimes for the spark

[a] Hadfield, R. A., Alloys of iron and nickel: Proc. Inst. Civ. Eng., vol. 138, 1899, pp. 1-124.
[b] Sexton, A. H., and Primrose, J. S., The metallurgy of iron.

poles in the spark plugs of internal-combustion engines, including automobiles, though commercial nickel wire is more commonly used.

High-nickel steels having 25 per cent or more of nickel and low carbon content (about 3 per cent) are austenitic in structure and in the natural state are softer and tougher than the medium-nickel martensitic steels.

High-nickel steel containing 24 to 32 per cent nickel in the form of wire is used for electrical resistance in small quantity, probably between 5 and 10 tons per year in this country.

The analysis and resistance of samples of Krupp nickel-steel resistance wire are shown below. This wire is used in electric toasters, cookers, irons, and similar devices.

Analysis and resistance of samples of Krupp nickel-steel resistance wire.

Sample No.	C.	Mn.	Si.	S.	P.	Cr.	Ni.	Specific resistance per cubic centimeter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Microhms.*
1	0.52	0.75	0.10	0.035	0.024	.....	30.6	87.9
2	.39	1.00	.70	.035	.025	.....	24.2	.....

Steel with 27 per cent of nickel is used in bits, stirrups, and spurs in riding harness because of its resistance to rusting. It will nevertheless rust slowly at ordinary temperature under conditions that strongly induce oxidation.

Steels containing more than 24 per cent of nickel are practically nonmagnetic in their ordinary condition, a rather remarkable fact when the high magnetic susceptibility of both iron and nickel alone is considered. The explanation that the critical point marking the change from the nonmagnetic to the magnetic state of iron is lowered by the nickel from about 700° C. (1,292° F.) to below ordinary atmospheric temperatures is, no doubt, sound as far as it goes. When 25 per cent nickel steel is cooled to −40° C. (−40° F.) it becomes magnetic, and retains its magnetism at ordinary atmospheric temperatures. On being heated to 580° C. (1,076° F.), however, the alloy reverts to the nonmagnetic state. This separation of 620° C. between the critical points marking the magnetic states in heating and cooling is great in comparison with the 25° to 50° C. of simple steels, and because of it this steel is classed as irreversible.

The nonmagnetic quality of high-nickel steels is not utilized chiefly because of its capacity for becoming magnetic, as described above, for if it happened to be cooled enough to make it magnetic it could not in most cases be easily demagnetized.

The fact that high-nickel austenitic steels have a somewhat lower modulus of elasticity than the low-nickel or simple steels does not

affect their value for the uses made of them. These steels also have low elastic limits though they are tough and show up well in the shock test. Nevertheless they are generally used not because of superior physical properties but because of their resistance to rusting and corrosion or their electrical resistance. With a carbon content of 0.25 to 0.30 per cent and 32 per cent nickel they are used in valves for gasoline motors with good results.

Nickel steel with 30 per cent of nickel is used in boiler tubes, particularly in marine boilers, for which it is admirable. These tubes are in the natural, not heat-treated state. They resist corrosion better than simple steel tubes and last three times as long. Hence their use is sometimes economical in spite of the much higher cost.

INVAR.

The 36 per cent nickel steel known as Invar is used to the extent of perhaps a few hundred pounds a year in clock pendulums, rods for measuring instruments, and such parts for which its exceedingly slight expansion and contraction when heated and cooled within the atmospheric range gives it a particular value. Nevertheless, its coefficient of expansion, even though small, is not negligible, and compensating means must be used in Invar clock pendulums and in the Invar balance-wheels of watches. A watch with an Invar balance-wheel varied 20 seconds per day during a temperature change of 40° to 90° F., the usual test change, a variation too great for a good watch. Some Invar has as low a coefficient of expansion as 0.0000008 per degree centigrade, and samples have been made that contracted slightly when warmed. The coefficient given indicates an expansion of 0.05 inch in a mile per degree C.

When Invar is heated to about 300° C. (572° F.) and higher its coefficient of expansion is greatly increased and its lack of expansion at ordinary temperatures appears to be merely a belated and not destroyed function. With excessive cold there is likewise a resumption of contraction.

PLATINITE.

Forty-six per cent nickel steel with 0.15 per cent carbon known as platinite, has about the same coefficient of expansion as platinum and glass and for that reason may be imbedded in glass without breaking the latter by a difference in expansion. It has been used in leading wires in the glass bases of electric incandescent lamp bulbs as a substitute for platinum which was formerly held to be indispensable. In those lamp bulbs the preservation of the vacuum is necessary and the joint between the wire and glass must be kept tight. Platinite has not been found wholly suitable for this purpose and is not now so used, a compound wire with a 38 per cent nickel-steel core encased in copper

and sometimes coated with platinum being now generally employed. The nickel-steel core if free will expand less than the glass and the copper more, so that each resists the other and the wire as a whole will have the desired rate of expansion. About 2 tons of nickel steel per year is used in this wire.

Many other alloys of iron and nickel have been studied by Guillet and others.[a] In fact the whole range has received more or less thorough attention, and much knowledge of scientific value has been gained concerning the varieties that so far have not found useful application.

BIBLIOGRAPHY ON NICKEL STEEL.

BROWNE, D. H. Nickel steel; a synopsis of experiment and opinion. Trans. Am. Inst. Min. Eng., vol. 29, 1899, pp. 569–648. Includes a bibliography dating from 1889.

SOUTHER, HENRY. Nickel and iron alloys. Mineral Ind., vol. 8, 1899, pp. 438–439. Briefly discusses the uses of nickel steel.

DUMAS, L. Recherches sur les aciers au nickel a haute teneurs. Ann. des mines, t. 1, sér. 10, 1902, pp. 357–561. Includes a bibliography.

PORTER, H. F. J. Nickel steel; its practical development in the United States. Cassier's Mag., vol. 22, 1902, pp. 480–500.

COLBY, A. L. A comparison of certain physical properties of nickel steel and carbon steel. 1903. Contains numerous bibliographies.

——— Nickel steel; its properties and applications. Proc. Am. Soc. Test. Mat., vol. 3, 1903, pp. 141–168.

——— Noncorrosive nickel-steel boiler tubes. Trans. Soc. Naval Arch. and Marine Eng., vol. 11, 1903, pp. 115–137.

WAR DEPARTMENT. Report of the tests of metals and other materials for industrial purposes, 1903. 1904, pp. 167–309. Discusses carbon and nickel-steel ingots.

GUILLAUME, C. E. Les applications des aciers au nickel. Paris, 1904.

JOHNS, COSMO. Notes on the production and thermal treatment of steel in large masses. Jour. Iron and Steel Inst., 1904, pt. 1, pp. 61–97. One table gives results of tests of hollow forged nickel steel forgings.

CARPENTER, H. C. H., HADFIELD, R. A., AND LONGMUIR, PERCY. Seventh report to the Alloys Research Committee; on the properties of a series of iron-nickel-manganese-carbon alloys. Proc. Inst. Mech. Eng., 1905, pts. 3 and 4, pp. 857–1041.

DIXON, EDWARD. Nickel and carbon steels. Engineering, vol. 82, July 6, 1906, pp. 22–23.

WATERHOUSE, G. B. The influence of nickel and carbon on iron. Electrochem. and Met. Ind., vol. 4, 1906, pp. 451, 482.

——— Nickel steel and its application to boiler construction. Iron Age, vol. 77, Feb. 8, 1906, pp. 490–491.

LAKE, E. F. The forging of alloy steels. Am. Machinist, vol. 30, pt. 2, Aug. 29, 1907, pp. 289–291.

GREGORETTI, U. F. La corazza "Krupp cementata" esaminata al microscopio. Rivista Marittima, vol. 41, November, 1908, pp. 227–238. Translation in Rev. mét., t. 7, 1910, pp. 260–285. Describes Krupp process of armor-plate manufacture at the Terni Steel Works.

PREUSS, ERNST. The strength of nickel-steel riveted joints. Carnegie Scholarship Mem., Iron and Steel Inst., vol. 1, 1909, pp. 60–142. Includes a bibliography.

[a] See bibliography following.

PREUSS, ERNST. Zur Kenntnis der Festigkeitseigenschaften des Nickelstahles. Stahl und Eisen, Jahrg. 29, Mar. 24, 1909, pp. 422–425.

WEBSTER, W. R. Nickel-steel eyebars for Blackwells Island Bridge. Trans. Am. Soc. Civ. Eng., vol. 64, 1909, pp. 289–302.

WADDELL, J. A. L. Nickel steel for bridges. Trans. Am. Soc. Civ. Eng., vol. 63, 1909, pp. 101–387.

GUILLET, LÉON, and RÉVILLON, LOUIS. Nouveaux essais au choc a témperatures variables. Rev. mét., t. 7, October, 1910, pp. 837–844.

BOHNY, F. Ueber die Verwendung von Nickelstahl im Brückenbau. Stahl und Eisen, Jahrg. 31, 1911, pp. 89–97, 184–193. Paper read before the Verein Deutscher Eisenhüttenleute.

MCWILLIAM, ANDREW, and BARNES, E. J. Some properties of heat-treated 3 per cent nickel steels. Jour. Iron and Steel Inst., 1911, pt. 1, pp. 269–293.

COLVER-GLAUERT, E., and HILPERT, S. The thermal magnetic transformations of 25 per cent nickel steel. Jour. Iron and Steel Inst., 1912, pt. 2, pp. 295–301.

CONE, E. F. Properties of nickel cast steel. Iron Age, vol. 90, Aug. 8, 1912, pp. 287–288.

HODGE, H. W. Tests of two large nickel-steel columns. Eng. Rec., vol. 67, March 1, 1913, pp. 234–235.

ARNOLD, J. O., and READ, A. A. The chemical and mechanical relations of iron, tungsten, and carbon, and of iron, nickel, and carbon. Proc. Inst. Mech. Eng., March–May, 1914, pp. 223–279.

ENGINEERING RECORD. Ultimate strength of carbon and nickel-steel models of Quebec Bridge members. Vol. 69, Mar. 21, 1914, pp. 333–336; vol. 70, Nov. 14, 1914, pp. 541–543.

NICKEL-CHROMIUM STEELS.

Nickel-chromium steels, known in the trade as chrome-nickel steels, are perhaps the most important of the structural alloy steels. Their field of usefulness is continually being enlarged by their application for new purposes and also by encroachment on the premises of some of the other alloy steels, notably of simple nickel steel, and they have almost wholly displaced nickel-vanadium and nickel-chromium-vanadium steels, which several years ago were in some considerable demand.

The amount of nickel-chromium steels produced in 1913 was thought to be about 100,000 tons of ingots, all made in the open-hearth furnace with the exception of 2,000 or 3,000 tons melted in crucibles and electric furnaces. The steel is made by 10 or 12 companies, 2 of which make it at several different plants.

Nickel-chromium steels are seldom used in any but a heat-treated condition. By suitable treatment pieces of small mass can be made to have as high physical properties as any steels known, with any elastic limit between 40,000 and 250,000 pounds per square inch, accompanied by ductility that is high as compared with its strength, as the ductility naturally lessens as the elastic limit increases.

Nickel-chromium steels can be made somewhat more cheaply than simple nickel steel of the same strength and ductility containing a smaller total of the alloying elements, and chromium is less costly than nickel.

COMPOSITION AND PROPERTIES.

The upper limit of nickel in useful chrome-nickel steels is about 3.5 per cent, and all useful steels of this class are pearlitic, according to Guillet.[a] According to the same authority, when a chrome-nickel steel is casehardened, the case is harder than that of a simple nickel steel.

Some of the defects and troubles of chrome-nickel steels are like those of simple nickel steels previously considered.

The composition and properties of six nickel-chromium steels in the natural or untreated state are given in the table following:

Composition and properties of nickel-chromium steels in natural or untreated state.

Sample No.	Composition.							Tensile properties.					Remarks.
	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Tensile strength.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	Ball hardness.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*		
1	0.55	0.41	0.22	0.03	0.02	1.53	1.14	96,000	75,000	66	31	185	Annealed.
2	.18	.27	.05	.04	.02	1.28	1.59	72,000	51,000	71	37	134	Do.
3	.15	.34	.13	.02	.01	1.28	.37	59,000	42,000	64	38	115	Do.
4	.29	.42	.07	.06	.02	3.86	1.48	.....	.....	.....	.....	.....	Natural.
5	.25	.32	.10	.03	.02	1.45	1.20	96,500	81,500	68	25	.....	Test piece.
6	.25	.32	.10	.03	,02	1.45	1.20	97,100	80,900	49	[a] 7	.....	Eyebar; full size.

[a] In 21 feet.

Sample 4 is from a plate similar to that used in the mast of the yacht *Vanitie*. It was not heat-treated but was used as rolled.

Samples 5 and 6 represent the same steel and show the relative properties of the small test piece and the full-size eyebar for a bridge the section of which was 14 by 2 inches. The difference in elongation is particularly noticeable, the great local stretch near the point of rupture being only a small part of the total length of the bar.

The composition and properties of six nickel chromium steels in the heat-treated condition were as follows:

Composition and properties of nickel-chromium steels in heat-treated condition.

Sample No.	Composition.							Tensile properties.					Heat treatment.	
	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Tensility.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	Ball hardness.	Temperature at which steel was quenched in water.	Temperature at which temper was drawn in air.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*		*° C.*	*° C.*
1	0.40	0.74	0.24	0.03	0.02	3.45	1.20	187,000	175,000	43	10	352	830	371
2	.36	.53	.11	.04	.01	1.55	.70	145,000	125,000	65	20	233	830	566
3	.21	.41	.22	.03	.02	3.52	1.11	110,000	75,000	66	24	215	830	682
4	.48	.44	.16	.01	.01	2.02	.98	212,000	186,000	46	10	445	843	427
5	.48	.44	.16	.01	.01	2.02	.98	140,000	120,000	61	18	287	843	649
6	.38	.28	.27	.02	.01	3.01	.65	114,000	90,000	69	25	266	843	649

[a] Guillet, Léon, Aciers nickel chrome: Rev. de mét., t. 3, 1906, pp. 462–484.

Any one of the first three samples could be given substantially the properties of either of the other two by varying the temperature of the second heating.

Most of the nickel-chromium steel goes into armor plate, projectiles, and automobile parts.

USE IN AUTOMOBILES.

For automobiles—and the practice might be advantageously extended to other fields—three grades of nickel-chromium steel are used. They are called low, medium, or high according to their contents of nickel and chromium. The carbon content may be varied for each grade within the limits shown in the following table:

Composition of nickel-chromium automobile steels.

Grade.	C.	Mn.	Si.	S.	P.	Ni.	Cr.
Low	0.20 to 0.40	0.65	Low.	0.045	0.04	1.25	0.6
Medium	.20 to .40	.65	Low.	.045	.04	1.75	1.10
High	.20 to .40	.65	Low.	.045	.04	3.50	1.50

These steels are almost invariably heat treated for use in automobiles, a wide range of properties being attainable by varying the heat treatment with each steel. The properties overlap those of steels of both harder and softer grades, so that a wide choice of properties is afforded as well as a choice of steels for the set of properties desired.

USE IN ARMOR PLATE.

An important use for chrome-nickel steel is in both thick and medium armor plate for war vessels. The thick heavy side armor, 6 to 14 inches thick, is face hardened by the well-known methods. A recent analysis of the body of a plate gave: C 0.33 per cent, Mn 0.32 per cent, Si 0.06 per cent, S 0.03 per cent, P 0.014 per cent, Ni 4 per cent, Cr 2 per cent, and its tensile properties after treatment were:

Tensile strength, pounds per square inch	101,000
Elastic limit, pounds per square inch	77,500
Elongation in 2 inches, per cent	24
Contraction of area, per cent	60

The results from such a great mass of metal were excellent.

Medium armor, between 3 to 5 inches thick, is rather similar in composition. It is not face hardened, but is given high properties as a whole by the heat treatment to which it is subjected. An analysis lately made gave: C 0.30 per cent, Mn 0.34 per cent, Si 0.13 per cent, S 0.03 per cent, P 0.03 per cent, Ni 3.66 per cent, Cr 1.45 per cent.

Its physical properties were those given below as sample 1. Sample 2 represented another chrome-nickel steel made for the same purpose, containing 3½ per cent of nickel.

	Sample 1.	Sample 2.
Tensile strength, pounds per square inch	119,000	138,000
Elastic limit, pounds per square inch	106,000	119,000
Elongation in 2 inches, per cent	22	22
Contraction of area, per cent	61	49

Such steel is most excellent for use on warships to form protective decks and barriers to protect from secondary battery fire. Chrome-nickel-vanadium steel is also used for this purpose, as noted elsewhere.

USE IN PROJECTILES AND IN RAILS.

Nickel-chromium steel is used in the manufacture of most armor-piercing projectiles.

Cubillo [a] cites a steel for projectiles, having 0.48 per cent C, 0.58 per cent Mn, 0.75 per cent Cr, 2.55 per cent Ni, 0.40 per cent Si, 0.04 per cent P. A test piece quenched in oil and tempered had an elastic limit of 129,400 pounds per square inch, a tensile strength of 150,300 pounds per square inch, and an elongation of 19 per cent.

For large projectiles Girod [b] prefers chromium-tungsten steel having 0.50 per cent C, 4 per cent Ni, 0 to 1.5 per cent Cr, and 0.25 per cent W.

It is curious that nickel is considered to improve the quality of shot although generally held to injure the quality of high-speed tool steels. In use there seems to be a parallel between the requirements of the two, except for the important and vital difference as to the required speed at which they respectively meet the metal to be penetrated. The speed of impact of the shot enables it to enter when no amount of pressure will effect the same result.

Chrome-nickel steel rails having 2 per cent of nickel and 0.7 per cent of chromium have been tried by several railroads, but with unsatisfactory results. They resisted wear well as compared with simple steel rails, but broke badly both transversely and lengthwise, so that they were considered unsafe and consequently were removed. They were made by the Bessemer process and were not heat treated.

DETAILS OF MANUFACTURE OF A SPECIFIC PIECE OF NICKEL-CHROMIUM STEEL.

Following is a description of the manufacture of a large shaft of mild chrome-nickel steel for marine purposes. A corrugated 35-ton ingot 45 inches in diameter was made of basic open-hearth steel

[a] Cubillo, L., Armor-piercing projectiles: Jour. Iron and Steel Inst., 1913, p. 251.

[b] Girod, P., Discussion of paper on armor-piercing projectiles: Jour. Iron and Steel Inst., 1913, p. 252.

having 0.24 per cent C, 0.70 per cent Mn, 0.013 per cent P, 0.015 per cent S, 0.18 per cent Si, 1.60 per cent Ni, and 0.32 per cent Cr. A few hundredths per cent of titanium was added in the ladle, but did not appear in the steel. The shaft when finished was 14½ inches in diameter, with an 8-inch hole through on the center line.

The steel was melted without the addition of ore late in the heat, a method that favored soundness and tended to allow the steel to clean itself of insoluble impurities such as oxides and silicates. The ingot was forged, annealed at 866° C. (1590° F.), bored, rough-turned, heated to 750° C. (1382° F.), quenched in oil, and drawn at 593° C. (1100° F.).

The shaft was merely raised to the drawing temperature, 593° C., when firing at once ceased, the furnace was closed, and the shaft allowed to cool with the furnace.

The averages of the tests, which were longitudinal, were as follows: Tensile strength, 83,300 pounds per square inch, elastic limit, 52,500 pounds per square inch, elongation in 2 inches 26 per cent, contraction 60 per cent. The results were excellent, though seemingly a lower drawing temperature, which would have resulted in a higher elastic limit, would have been justified.

MAYARI STEEL.

A so-called natural chrome-nickel steel is now made from certain ores mined at Mayari, Cuba. The ores carry enough nickel to give 1.3 to 1.5 per cent of nickel, and enough chromium to give 2½ to 3 per cent of chromium in the crude iron smelted therefrom. When the iron is converted into steel by the pneumatic or open-hearth processes, the nickel is practically all present in the steel, but the chromium is of necessity largely wasted by being oxidized.

Steel made in part of Mayari iron is giving good service in rails and particularly in track bolts, which are heat treated to give the metal an elastic limit of 75,000 pounds per square inch.

Why these rails are satisfactory when other chrome-nickel steels were not has not been explained. The chief differences seem to be (1) that these Mayari steel rails have less of the alloying elements because Mayari iron is used only in part in them, and (2) that the steel is made in the open-hearth furnace.

The use of steel containing Mayari iron is increasing, and the demand is enough to induce the production synthetically of steels of the same composition by adding nickel and chromium to simple steels in the Mayari proportions.

The Mayari steels are not included in the estimated quantity of chrome-nickel steels made, as already given. In fact it is likely that in the near future the tonnage of Mayari steels will surpass that of all the other chrome-nickel steels taken together.

CASTINGS OF NICKEL-CHROMIUM STEELS.

Castings are made also of chrome-nickel steel and may be used in the annealed or heat-treated condition.

Composition and properties of chrome-nickel steel castings.

Sample No.	Composition.							Tensile properties.				Condition.
	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Tensile strength.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*	
1.....	0.30	0.41	.....	0.04	0.03	3.64	1.49	91,500	45,500	24	16.5	Annealed.
2.....	.33	.39	.....	.04	.03	3.58	1.61	90,500	46,500	27	18.5	Do.
3.....	.30	.20	0.35	.....	.....	2.50	.50	110,000	80,000	30	20	Heat-treated.

BIBLIOGRAPHY ON NICKEL-CHROMIUM STEEL.

GUILLET, LÉON. Aciers nickel chrome. Rev. mét., t. 3, 1906, pp. 462–484.

LAKE, E. F. Nickel-chrome steel. Machinery (N. Y.), vol. 13, July, 1907, pp. 615–617.

SCHAEFFERS, JOSEPH. Alloy-steel tubing for the automobile industry. Horseless Age, vol. 26, Dec. 7, 1910, p. 782.

IRON AGE. Mayari steel; its properties and uses. Vol. 89, Jan. 4, 1912 pp. 69–72.

SILICON STEELS.

Although silicon is an ingredient of practically all steels its presence is often accidental or unavoidable, and if it is added to simple structural and tool steels the purpose is to promote soundness rather than to improve the properties of the finished steel. In tool steels silicon is always present, and in times past high-silicon steels have been advocated for tools, but they are not now so used in a commercial way.

MANUFACTURE OF SILICON STEEL.

Silicon steels are generally made in the open-hearth furnace, preferably on an acid hearth, as the acid slag does not waste the silicon in the final additions as rapidly as does a basic slag that contains free oxide of iron, and therefore the final content of silicon desired may be more closely controlled.

Silicon in true silicon steels must be added to the charge only a short time before teeming, as any oxygen that reaches the metal will largely be taken up by the silicon which will be wasted by burning to silicic acid (SiO_2). When so added to a bath in proper condition as to temperature and amount of dissolved oxygen or oxides the silicon will overwhelm the gases in solution, and the steel as cast will be free from blowholes and with a maximum tendency to pipe.

Because of the large proportion of silicon in silicon steels and because of the short time allowable after the silicon has been added to the bath it should be added in the heated or molten state.

Silicon steels containing about 2 per cent of silicon or more roll very "dry," that is, they are liable to be cracked by the heavy reductions of the first passages through the blooming mill.

PROPERTIES OF SILICON STEELS.

Silicon steel containing 0.20 per cent of carbon may be rolled if the silicon content is less than 7 per cent. With 0.90 per cent carbon it may be rolled if the silicon is less than 5 per cent. With a silicon content higher than 5 per cent the metal is useless.[a] In structural steels the effect of the silicon is to raise the elastic limit to a moderate degree. Silicon lowers the coefficient of expansion of steel somewhat as nickel does.

Composition and properties of structural silicon ("silico-manganese") steels.

Sample No.	Description.	C.	Si.	Mn.	S.	P.	Tensile strength.	Elastic limit.	Elongation.	Contraction.	Ball hardness.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Pounds.*	*Pounds.*	*P. ct.*	*P. ct.*	
1	Automobile springs	0.50	2.0	0.70	0.04	0.03	.....	.....	.....	.....	.....
2	Springs treated....	.47	1.83	.70	.01	.01	254,000	230,000	9	40	.....
3	Carriage axles.....	.50	1.90	.70	.04	.04	.....	.....	.....	.....	.....
4	Test piece, natural condition	.48	1.4	.45	.....	.....	113,760	71,100	17	.....	.....
5	Test piece, treated.	.48	1.4	.45	.....	.....	177,750	149,310	14	.....	.....
6	Test, treated.....	.50	1.75	.65	.....	.....	.....	198,700	8.5	21	418
7	Annealed.....	.36	1.27	.57	.03	.02	94,500	59,750	25	48	.....
8	Drawn at 427° C...	.36	1.27	.57	.03	.02	182,200	160,850	12.5	34	.....
9	.....do.....	.31	2.39	.48	.03	.05	134,750	104,700	22	55	.....

The treated test piece comprising sample 5 was heated to 954° C. (1,750° F.), quenched in water, and drawn at 427° C. (800° F.). The hardening temperature of samples 8 and 9 was probably about the same as that of sample 5.

USES OF SILICON STEELS.

The dividing line between silicon-treated steels and silicon-alloy steels is not clearly defined, but the latter are used for several important purposes. In structural lines their employment is limited, as their properties can, generally speaking, be readily equaled or excelled by simple steels.

The chief structural use of silicon-alloy steel is in springs of the leaf type for automobiles and other vehicles. The silicon is considered to make the springs somewhat tougher so that they are less liable to break in service than springs of simple steel. In the trade this steel is called silico-manganese steel, though its content of manganese is

[a] Guillet, Léon, Aciers au silicium: Rev. mét., t. 1, 1904, p. 67.

usually no more than is common in simple steels and not enough to properly cause the steel to be classified as a manganese-alloy steel.

In electricity, an important use for silicon-alloy steel is in the cores of static transformers. With the exception of manganese most of the elements employed in making alloy steels, although not greatly decreasing the magnetic susceptibility of the iron that contains them, lower its hysteresis loss. Silicon is the element most used for that purpose because it is the cheapest, but aluminum, phosphorus, nickel (3½ per cent), and tungsten have a similar effect.

The silicon content in silicon transformer metal is usually between 3½ and 4½ per cent or, more exactly, 4 to 4¼ per cent. Some 25,000 tons was used in 1913 for this purpose. The steel is rolled into thin sheets which, for one large user, are 0.014 inch thick; the transformer cores are built up of these sheets, which are cut to shape separately by stamping. For low induction the permeability of this steel is nearly as great if not greater than that of any other variety of iron or iron alloy known, and its hysteresis loss is less than that of any other of nearly as low cost.

The results of an analysis of a transformer core made of silicon-alloy steel are as follows: C, 0.08 per cent; Si, 4.18 per cent; Mn, 0.11 per cent; S, 0.06 per cent; P, 0.01 per cent; Al, 0.01 per cent.

Silicon steels can not be case hardened as the silicon retards the absorption of carbon; the silicon content must therefore be low, not over 0.04 per cent, in steel intended to be so treated.

BIBLIOGRAPHY ON SILICON STEEL.

HADFIELD, R. A. On alloys of iron and silicon. Jour. Iron and Steel Inst., 1889, pt. 2, pp. 222–255.

HEYN, E. Einfluss des Siliciums auf die Festigkeitseigenschaften des Flussstahls. Stahl und Eisen, Jahrg. 21, May 1, 1901, pp. 460–464.

GUILLET, LÉON. Aciers au silicium. Rev. mét., t. 1, 1904, p. 67.

GONTERMANN, W. Iron-silicon-carbon alloys. Jour. Iron and Steel Inst., vol. 83, 1911, pp. 421–475.

RUDER, W. E. Grain growth in silicon steel. Bull. Am. Inst. Min. Eng., December, 1913, pp. 2805–2822.

HIGH-SPEED TOOL STEELS.

High-speed tool steels, also called rapid steels, have in the past fifteen years worked a remarkable revolution in the machine-shop business of the whole world, affording largely increased outputs and commensurate lower costs. As a consequence they are now being used very generally and in some shops almost exclusively for machining iron and steel as well as some other metals by cutting operations by machine tools.

The revolutionary feature wherein tools made of these steels differ from and exceed in service the tools formerly used is their ability to

maintain a sharp strong cutting edge while heated to a temperature far above that which would at once destroy the cutting ability of a simple steel tool. Because of this property a tool made of high-speed tool steel can be made to cut continuously at speeds three to five times as great as that practicable with other tools, and when, as the result of the friction of the chip on the tool, it may be red-hot at the point on top where the chip rubs hardest, and the chip itself may, by its friction on the tool and the internal work done on it by upsetting it, be heated to a blue heat of 296° C. (565° F.) or even hotter to perhaps 340° C. (644° F.).

This property of red-hardness or ability to retain hardness at a red heat may be imparted to steels of suitable composition, comprising chromium and tungsten, by a unique heat treatment to which they may be subjected. This treatment, described later, was introduced by F. W. Taylor and Maunsel White, as has been described by Taylor,[a] at the works of the Bethlehem Steel Co. in 1899, and tools so treated were shown at the Paris Exposition in 1900, where they naturally created a great sensation among those familiar with the machining of metals. White, when giving the writer his first knowledge of these tools in 1899 or early in 1900, said that a young man in the Bethlehem shop had lighted a cigarette with a newly cut chip, a statement that seemed almost unbelievable at the time.

In this country in 1913 about 7,000 tons of high-speed or rapid tool steels was made by some 15 makers, that output requiring about 8,000 tons of ingots.

MANUFACTURE OF HIGH-SPEED TOOL STEEL.

High-speed tool steels are all made by the crucible or electric-furnace process. Except at one works, the crucibles or pots are made of graphite. The average life of the crucibles or pots varies in different works from six to nine melts. Some makers use clay-lined graphite pots in melting this steel to prevent or hinder the absorption of carbon from the pot. The clay lining is only one-eighth to three-sixteenths of an inch thick and is sometimes cut through on the second or third melt; in that event the molten steel may absorb too much carbon. Other makers use a graphite pot twice—first for melting other kinds of steel and then for rapid steel when the inner surface of the pot is somewhat slagged over, because of which the absorption of carbon is much less than when the pot was new.

The large producers use gas-fired melting furnaces for heating the pots, which are charged into the furnace at the top. Each melting hole contains six pots and each pot takes a charge of 90 or 100 pounds.

[a] Taylor, F. W., On the art of cutting tools: Trans. Am. Soc. Mech. Eng., vol. 28, 1906, pp. 31-350.

The charge is melted and then "killed" in the usual way by being held 30 to 40 minutes. Such procedure, together with the presence of the large amount of alloy, regularly gives sound piping steel. If run continuously a furnaceful of pots will be melted about every four hours.

In packing a pot with a charge for rapid steel the tungsten must be placed on top of the charge—as with simple tungsten steel—to guard as far as possible against the tendency of the tungsten to settle because of its high specific gravity. That tendency seems to be less with the rapid steels than with the simple tungsten steels. Whether the chromium of the former influences or hinders the settling of the tungsten is conjectural.

The smaller ingots, which are made from one pot of steel, vary from 3½ to 5 inches square. The steel is sometimes teemed directly into the mold by hand-pouring, but in some works clay funnels are placed on top of the mold to direct the stream down the center of the mold to avoid cutting its wall, as might happen if the stream impinged on it. Funnel pouring is also advantageous when two pots are to be combined to make a larger ingot, as the steel can be poured into the funnel from opposite sides at the same time, a procedure that will mix the liquid steel and give a more uniform ingot than when one pot follows another, as in hand pouring when no funnel is used.

Some of the larger producers of rapid steels use for casting a large bottom-pouring ladle into which the steel is poured from the pots of one or more furnaces, and from which the ingots are top-cast; that is, the molds are filled from the top. This method presents the advantages that (1) the product is more uniform; (2) individual pot charges, which might not be of the prescribed composition or might be otherwise unsatisfactory, are merged with the others without detriment to the whole; (3) large ingots are easily made; (4) one analysis serves for the whole number of pots; (5) one test serves for the whole ladleful of steel. It is a matter of experience that complaints from customers became much less frequent after the introduction of the ladle for casting this steel.

The strong tendency of rapid steel to pipe is checked considerably in most plants by the use on each ingot of a hot "dozzler," which is a clay ring preheated red hot, that is placed on the ingot top and filled with molten steel. This arrangement keeps the top of the ingot molten long enough so that the pipe is of diminished size and nearly or quite all contained within the part of the ingot surrounded by the dozzler. The proportion of the ingot to be rejected on account of the pipe is therefore much decreased. The molds are usually closed at the bottom end and are either made with parallel walls or tapered so that the ingot is larger at the top than at the bottom. The molds

must be split when the walls are parallel, and are sometimes split when the ingots are tapered.

High-speed tool steel as cast has a coarse structure and dark color as compared with the structure and color of simple steels of the same carbon content. A corner is broken from the top of each ingot, to show the grain, and the ingots when hand-poured directly from the pots are classified by the eye as in the production of simple crucible steels. If the ingots are cast from the large ladle a test is taken for analysis which determines the disposition of the whole ladleful of steel.

As a rule the ingots show a strong columnar structure or arrangement of crystals whose axes are normal to the cooling surface. Some makers refer to the structure as a "lemon structure," the crystals of the metal being thought to resemble the cells forming the pulp of a lemon. If the casting temperature is lower than usual, this lemon structure may be absent, and in that case the interior of the ingot will have a much finer grain than the ingots cast at the usual higher temperature. The subsequent heating and working of the steel entirely destroys the crystalline structure of the ingot, and the worked steel, on a fresh fracture, shows a most beautiful porcelanic structure.

The ingots run from 3½ by 3½ inches to 16 by 16 inches, but most of them are from 5 by 5 inches to 9 by 9 inches. For hot-working they are heated in a furnace chamber having a temperature of about 1,180° C. (2,156° F.). At this high heat the steel may be worked satisfactorily under the hammer or press and may be quickly worked down to the dimension desired.

COMPOSITION OF HIGH-SPEED TOOL STEELS.

The tendency of the makers is toward a somewhat uniform composition as regards the contents of the alloying elements, whose benefits have become fairly well known, and whose use as a consequence may be considered as established. Specifically, these alloying elements are tungsten and chromium. The addition of vanadium and cobalt in important proportions is considered by some makers to give distinct improvement to high-speed steel, and some vanadium is almost always present.

The following analyses are of steels recently made, most of which are considered to be good commercial steels:

Results of analyses of high-speed steels made in 1913 or 1914.

Sample.[a]	C.	Mn.	Si.	S.	P.	Cr.	W.	V.	Co.	Ni.	Mo.	Remarks.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
A	0.65	0.15	0.20	0.02	0.03	4.75	17.50	0.90	.....	.....	.....	
B—1	.66	.27	.14	.04	.05	4.51	17.48	.70	4.22	0.17	.....	
B—2	.74	.31	.13	.04	.02	4.20	15.63	.67	2.70	.....	.....	
B—3	.63	.14	.07	.04	.05	4.26	17.16	.45	3.80	.20	.....	
B—4	.69	.34	.14	.03	.04	5.28	16.35	.64	5.28	.....	.....	
C—1	.66	.22	.17	.03	.02	3.44	16.51	.73	.....	.....	.....	
C—2	.64	.21	.16	.03	.03	3.30	16.06	.66	4.02	.....	.....	
C—3	.67	.33	.25	.02	.02	3.85	16.06	.70	.....	.....	.....	
D—1	.75	.28	.36	.03	.....	4.10	19.00	.75	.....	.....	.....	Good.
D—2	.68	.38	.40	.03	.....	4.65	17.85	.53	.....	.....	.....	Inferior.
D—3	.69	.36	.38	.04	.....	4.67	17.90	.50	.....	.....	.....	Do.
D—4	.57	.20	.26	.02	.03	4.82	15.38	.50	.....	.....	.....	Do.
E—1	.61	.23	.35	.04	.....	4.10	17.20	1.00	.....	.....	.....	Good.
E—2	.68	.45	.40	.04	.....	4.00	14.26	1.09	.....	.....	.....	Inferior.
E—3	.70	.50	.39	.05	.....	4.08	14.50	1.07	.....	.....	.....	Do.
E—4	.60	.23	.12	.03	.02	3.90	17.27	.90	.....	.....	.....	Do.
F	.64	2.29	.12	.02	.01	4.39	16.09	.59	.....	.28	.....	
G	.72	.37	.18	.03	.02	4.50	13.30	2.50	.....	.....	.....	
H—1	.77	.16	.21	.02	.02	4.05	18.64	1.35	.....	.....	.....	
H—2	.67	.16	.20	.02	.02	4.66	13.86	1.08	.....	.....	.....	
I	.64	.23	.29	.02	.02	4.57	19.10	.54	.....	.....	.....	
J—1	.64	.30	.26	.02	.01	2.93	18.71	1.22	.....	.....	.....	
J—2	.71	.14	.26	.03	.03	2.97	18.21	.97	.....	.....	.....	
K—1	.55	Tr.	.23	.02	.04	4.46	16.05	.80	4.72	.....	0.72	
K—2	.70	Tr.	.18	.01	.02	4.25	15.50	.88	4.72	.18	.67	
K—3	.74	.31	.13	.04	.02	4.20	15.63	.67	2.70	.....	.....	

[a] Samples A to I represented American steels, the numerals indicating different samples from the same maker; sample J represented an English steel; sample K represented a German steel.

Samples D—1 and E—1 gave excellent results in a competitive test, whereas samples D—2, D—3, E—2, and E—3, manufactured by the same makers, gave distinctly inferior results in the same shop.

The occurrence of nickel in four of the samples may have been accidental, having been due to nickel in some of the scrap steel used in the charge. Most makers now put in vanadium, and steel like that represented by sample G, which had the highest vanadium content of all the samples represented in the table, was the winner in a recent competitive test.

The average specific gravity of the steels represented in the table was about 8.8, the increase over the specific gravity of iron being due chiefly to the tungsten content.

There are so many factors beside the ultimate composition that affect the value of rapid tool steels that no conclusion can be drawn from the analysis alone. The melting, hot working, and heat treatment all must be done correctly or the final result will not conform to expectations.

CARBON IN HIGH-SPEED TOOL STEEL.

The proportion of carbon aimed at in high-speed tool steels is about 0.65 per cent, which in a simple steel would not be enough to give the maximum hardness even if the steel were heated above the critical point and quenched in water, and still less so when the steel is cooled as slowly as these steels are in their treatment. This shows that the carbon acts in a different way from what it does in simple steels, as is discussed later.

TUNGSTEN IN HIGH-SPEED TOOL STEEL.

Tungsten is well established as a most important if not indispensable ingredient of commercial tool steels, being almost or quite universally used in quantity therein. The best proportion of tungsten, all things considered, seems to lie between 16 and 20 per cent, the tungsten content in 95 per cent of all the American steels coming within these limits. Some published analyses of European high-speed tool steels show a higher content of tungsten than this, but American makers generally agree that any tungsten in excess of 20 per cent adds nothing to the usefulness of the steel, and they therefore make that proportion the upper limit of the amount added. One effect of the tungsten is that the best percentage of carbon in rapid steel is but about half that required in simple tool steels intended for the same kind of service.

CHROMIUM IN HIGH-SPEED TOOL STEEL.

The effect of chromium in high-speed tool steel, as in other steels, is undoubtedly as a hardener, entering into the double carbide of tungsten and chromium which gives or causes the proper cutting edge. Although the proportion of this element present in these steels varies considerably, it is always large, perhaps never less than 2 per cent or more than 6 per cent in American steels, and in European steels the upper limits is at least 9 per cent.

MOLYBDENUM IN HIGH-SPEED TOOL STEEL.

The use of molybdenum in high-speed tool steels is being generally discontinued. Some makers for years manufactured molybdenum tool steels, but as a rule they have either wholly discontinued its use or use a much smaller proportion than formerly, employing it as an auxiliary rather than a major constituent.

The effect of molybdenum is similar to that of tungsten, but is more intense in that 1 per cent molybdenum is currently considered to give about the same or greater hardening effect than 2 per cent of tungsten. It gives a fine cutting edge.

Various reasons are assigned for the discontinuance of the use of molybdenum in these steels. Taylor[a] found that molybdenum in rapid steels caused irregular performance; that steels of nearly the same composition and having had seemingly the same treatment gave large variations in the cutting speeds they would stand. One user specifies no molybdenum because it causes the tools to crack in quenching. A maker objected to molybdenum because molybdenum steel was apt to be seamy and to contain physical imper-

[a] Taylor, F. W., On the art of cutting metals: Trans. Am. Chem. Soc., vol. 28, 1906, pp. 31-350.

fections. A maker of ferro-alloys understands that molybdenum steel deteriorated upon repeated heating for dressing and treatment, seemingly because the molybdenum disappeared from the outer parts of the steel where it was exposed to the heat and where any volatile constituent could escape. This phenomenon recalls a proposal of Moissan to use molybdenum as a means of freeing molten iron of oxygen, as he found that the oxide of molybdenum was much more volatile than the metal itself. It may be, therefore, that the molybdenum at the surface is oxidized and volatilized, but for this waste to extend to any considerable depth implies either that molybdenum moves through the heated steel to reach the oxygen of the air, or, as is more likely, that the oxygen of the air penetrates the steel, reaching the molybdenum and oxidizing it, the volatile oxide escaping from the steel.

The cost of molybdenum when its use was most general was much more than that of tungsten. Because of the falling off of the demand in recent years, however, the price of molybdenum has fallen to about that of tungsten, or to a fraction of what it was a few years ago.

It has been observed that in the Eggertz color determination a high molybdenum content (4 to 8 per cent) causes "missing" or invisible carbon when the content of latter element is high (0.4 to 1.2 per cent).

VANADIUM IN HIGH-SPEED TOOL STEEL.

Vanadium is used for high-speed tool steel in varying amounts, most makers using at least 0.5 per cent, although some run the vanadium content up to 1½ or 1¾ per cent, or even more, considering that such an addition increases in an important degree the value of the steel for tools.

The effect of vanadium is considered to resemble in some ways that of chromium in increasing the hardness or red-hardness of the cutting edge. One maker makes two kinds of high-speed tool steel, the essential difference between the two being that one contains about 1½ per cent of vanadium and thereby commands a higher price, whereas the other has little of this element, both kinds being intended for substantially the same service.

High-speed steels containing vanadium are generally classed as "superior" steels and many though not all makers and users consider them distinctly better than the "standard" steels containing no vanadium, both on account of their actual cutting qualities at high speeds and on account of the length of time a tool will cut before it needs regrinding. The true value of vanadium in rapid steels must probably be held as not yet fully determined. The

analyses given in the table show that all the samples contained vanadium but in greatly varying amounts.

COBALT IN HIGH-SPEED TOOL STEEL.

Cobalt now threatens to change tool-steel manufacture because of the properties it imparts. The recent great decline in price following the increase of the supply from the silver ores of the Cobalt district in Ontario naturally led to its trial as a steel-alloying element, and some most excellent high-speed steels containing, in addition to the usual ingredients, about 4 per cent of cobalt, have been obtained. This result was hardly to have been expected in view of the experience with nickel, which cobalt much resembles, as nickel has been condemned by nearly every manufacturer as not being a desirable ingredient of high-speed tool steels, because of the effect it has of making the edge soft or "leady." The cobalt steel, however, has shown, in some products at least, increased ability to hold its edge in work.

One user of cobalt steel found it better suited for turning manganese steel than any other steel he tried, his success being so marked as to make it practically a commercial operation. Manganese steel, as noted elsewhere, is so hard as to be considered practically unmachinable, the usual practice having been to finish it by grinding when necessary. Another user found that an imported cobalt high-speed steel proved excellent for cutting a hard nickel-chromium steel in a lathe, whereas the same steel in a cold saw was not satisfactory. The direct reason seemed to be that this steel to do its best work must be run nearly if not quite red hot; at least that was the condition in which it was used in the lathe, while in the cold saw its temperature was not raised to an important degree, and when cold its properties were different than when it was hot. This behavior is more or less common to high-speed steel as is mentioned later.

The valuable effect of cobalt is claimed to be that it increases the red-hardness of high-speed tool steel, enabling the steel to cut at a higher speed.

COPPER IN HIGH-SPEED TOOL STEEL.

Copper has been considered to be highly injurious in high-speed tool steel, even as little as 0.05 per cent being inadmissible; and it is thought to be particularly harmful if much sulphur is present in the steel; also the higher the carbon content the more harmful is the copper.

SULPHUR AND PHOSPHORUS IN HIGH-SPEED TOOL STEEL.

Sulphur and phosphorus, which are so deleterious in simple tool steels, are considered to be somewhat less so in high-speed steels, in which the effect is either modified or else masked by the large quantities of other ingredients. Some commercial brands of high-speed steels have as much as 0.05 per cent of each of these impurities, to which no inferior quality is attributable.

STELLITE.

Stellite, though a competitor of high-speed steels, is not within the scope of our subject, but a recent analysis is given of a sample for such interest as it may have in relation to cutting steels.

Analysis of stellite.

Constituent.	Per cent.
Co	59.50
Cr	10.77
Mo	22.50
C	.87
Si	.77
Mn	2.04
S	.084
P	.040
Fe	3.11
W	0
Ni	0
	99.684

HEAT TREATMENT OF HIGH-SPEED TOOLS.

The heat treatment given to high-speed steels for the commoner uses as lathe and planer tools has generally been simplified to heating to incipient fusion and quenching in oil. Cooling by an air blast and double treatment, which were formerly recommended, are now not common, except that a second (drawing) heating is given to milling cutters and similar tools, the temperature imparted to the tool depending on the material to be cut.

The treatment is usually done by the blacksmith who heats the tool in his forge fire and then immerses it in a tank containing enough oil so that its temperature does not rise materially. Ten gallons of oil is a common quantity to use when the size and number of the tools is moderate, as in most shops. The fire is a deep compact coal fire, the coal in the center where the tool is heated being pretty thoroughly coked, that is, most of its volatile matter distilled out. This manner of heating has the advantage that free oxygen does not get at the tool to oxidize it, but its environment is nonoxidizing or even reducing, owing to the presence of an excess of burning carbon

surrounding the tool. Any flame is more or less oxidizing, at least unless heavily charged with smoke or free carbon, and a piece of steel heated directly by a flame as in the ordinary heating chamber of a furnace is likely to be somewhat oxidized on its surface, the depth to which the oxygen penetrates varying according to the conditions, particularly the temperature, the access of air, and the length of time. Heating in a muffle will also result in oxidizing the steel unless extraordinary precautions are taken to keep out oxygen or to consume all that enters. The temperature of quenching, usually about 1,260° C. (2,300° F.), is determined by the fusion of the scale and its visible collection into drops or beads on the surface of the tool.

Quenching is done by quickly plunging the heated tool into the oil as soon as it has reached the desired temperature and moving it about in the oil until cold. Cooling in oil is thought by some to give a better tool than cooling in the air blast, one reason seemingly being the protection of the steel from free oxygen while it is hot enough to be oxidized thereby. The oxygen of the air blast forms a scale of oxide on the hot steel and the oxygen probably penetrates the metal below the scale to some extent, injuring the quality as deep as it goes. A tool on its second grinding when the oxidized metal is removed may then give better service than on the first, unless the first grinding has for that reason been heavy enough to remove the oxidized metal.

In some shops, however, the original treatment recommended by Taylor and White [a] is given, the cutting edge of the tool being heated to incipient fusion and then immersed in a bath of melted lead at about 565° C. (1050° F.). The heating is done in a small furnace over a deep coke fire, blown by an air blast, so that the environment of the tool while being heated is substantially non-oxidizing. Flames of carbonic oxide play out of the openings through which the tools are inserted, indicating little if any free oxygen within. In these shops, however, milling cutters and other tools that are machined to a particular form are treated by heating them to a slightly lower temperature, in order not to damage the cutting edges, and then plunging them into cold oil.

When cooled to the temperature of the lead it is taken out and placed in an air blast to complete the cooling. Some tools desired to be especially tough so as not to break in service are given a second heating to 565° C. and then cooled in the open air or air blast if saving time is important.

Rapid steel when well annealed will bend considerably without breaking, even in as large a section as 2½ by 1¼ inches, the bending being edgewise, as in a tool at work.

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[a] Taylor, F. W., On the art of cutting metals: Trans. Am. Soc. Mech. Eng., vol. 28, 1906, p. 228.

Gledhill[a] found that one of these steels after having been annealed 12 to 18 hours at 760° C. (1400° F.) had a tensility of 129,200 pounds per square inch, an elastic limit of 89,600 pounds per square inch, an elongation of 18 per cent in 2 inches, and a contraction of area of 35 per cent. The ductility is rather high and would enable a tool to be bent considerably without breaking. Such annealed steel may be rather easily machined for making milling cutters and other shapes that require machining.

Carpenter[b] found that the higher the temperature from which rapid steel is cooled the more it resisted etching for metallographic work. He also found that no tempering change occurred when it was reheated at a temperature of less than 550° C. (1022° F.) to a visible red in the dark, indicating a stability that is doubtless the cause of its property of red hardness.

Whether a rapid steel is made harder by the heat treatment given it depends somewhat on the condition of the bar before treatment. If it has previously been annealed, the treatment hardens it, whereas heat treatment may not harden a piece in the natural state. Taylor[c] found that some tools having useful red hardness could be filed rather readily. Edwards[d] on the other hand found treated high-speed steels to be exceedingly hard—as hard as any steel could be made by quenching. Gledhill[e] found that high-speed steel was good for turning chilled rolls which are extremely hard and require to cut them the hardest kind of tool.

Trials on window glass of a number of different rapid steels showed that the cutting edge of some but not of all would scratch it. The same was true of the untreated ends of the same tools, as some would and some would not scratch the window pane.

The hardness of the steel when cold is not the determining factor of usefulness in any case. It is the hardness when heated under conditions of work.

The cutting edge of a rapid-steel tool at work is probably never as hot as the metal just back of it, where the heating caused by the friction of the chip, as it is deflected and rubs hard on the tool, is most intense. The edge itself is kept relatively cool by the cold metal flowing upon it.

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[a] Gledhill, J. M., The development and use of high-speed tool steel: Jour. Iron and Steel Inst., pt. 2, 1904, pp. 127-181.

[b] Carpenter, H. C. H., The types of structure and the critical ranges on heating and cooling of high-speed tool steels under varying thermal treatment: Jour. Iron and Steel Inst., pt. 1, 1905, pp. 433-473.

[c] Taylor, F. W., On the art of cutting metals: Trans. Am. Soc. Mech. Eng., vol. 28, 1906, pp. 31-350.

[d] Edwards, C. A., Function of chromium and tungsten in high-speed tool steel: Jour. Iron and Steel Inst, pt. 2, 1908, pp. 104-132.

[e] Gledhill, J. M., loc. cit.

THEORY OF HIGH-SPEED STEELS.

Carpenter [a] found the heating and cooling curves of a rapid steel to be radically different from each other, and also that the cooling curve when the steel was cooled from 930° C. (1706° F.) was greatly different from that when the steel was cooled from 1250° C. (2282° F.). When the steel was cooled from 930° C. the curve had an abrupt jog, which showed a great retardation in rate of cooling occurring between 700° C. and 750° C. (1292° F. to 1382° F.). The jog did not occur when the steel was cooled from 1250° C., 320° higher, the line representing variations in rate of cooling being nearly straight. The rate of cooling to get these curves was slow or at least not accelerated, and one can not say what the curves would be like if the rate of cooling were hastened, as in quenching, but the curves obtained seem to throw much light on the question. The property of red hardness seems to be connected with the elimination of the great retardation mentioned.

The following explanation, based on the work of Carpenter [a] and Edwards [b], of the properties of high-speed steels, seems to be helpful or even satisfactory:

Their researches on the heating and cooling of these steels have shown that such steels have an extraordinary stability of composition after they have been heated to 1,200° C. (2,192° F.) or more, and that a second heating of 550° C. (1,022° F.) has no softening or drawing effect. It seems fairly evident that red-hardness depends on or is the natural result of these facts.

At a temperature higher than 1,200° C. (2,192° F.) a double carbide of chromium and tungsten is formed, which persists largely even when the steel is cooled slowly as in the open air, and more so when cooling is accelerated. This double carbide imparts to the steel a high degree of hardness and is stable at all temperatures up to 550° C. (1,022° F.) or somewhat higher. At 550° C. the steel has a low red color visible in the dark.

If the above theory be true then at a temperature of 1,200° C. (2,192° F.) the chromium and tungsten must have a stronger affinity for carbon than iron has, whereas at lower temperatures, say from around 930° C. down to the critical point, the affinity of carbon for iron is slightly stronger than that of either chromium or tungsten or both, and the carbon then exists wholly or in part as carbide of iron, or a complex carbide of iron with one or both of the other elements.

Carbide of iron, or hardening carbon which causes the hard condition of iron in simple steel that has been quenched from a temperature higher than the critical point, is unstable at even slight elevations of temperature above atmospheric temperature, its unstable-

[a] Carpenter, H. C. H., loc. cit. [b] Edwards, C. A., loc. cit.

ness increasing with the degree of heat, though not being proportional thereto. Boynton[a] has shown that between 400° C (752° F.) and 500° C. (952° F.) the amount of change and consequent softening is much greater than at other temperatures, either lower or higher.

The proportion of carbon in rapid steel should perhaps be only as much as will combine with the chromium and tungsten at 1,200° C. (2,192° F.) and leave none to exist as unstable hardening carbon of hardened simple steel.

TESTING AND USING HIGH-SPEED STEEL.

A reliable and inexpensive method of quickly testing high-speed steels to show their value is much needed, as Taylor[b] has explained. Herbert[c] and Edwards[d] have used and recommended machines and methods that lessen the time and trouble of testing, but no test seems to take the place of a trial at actual work because the performance of a tool in one line of work with certain conditions may not be foretold positively by its performance in another with different conditions. Among the reasons are that (1) sometimes greater durability is obtained by changing, that is, increasing or lessening, the speed of the cut, thus changing also the temperature of the tool or (2) a given tool when used at its best speed may be excellent for cutting a certain material, yet prove inferior to another tool for cutting a different material. Thus if selected as the best by trial for cutting a 0.20 per cent carbon steel it may be surpassed by others in cutting a 0.70 per cent carbon steel.

Physical tests of rapid steels at different temperatures up to 800° C. (1,472° F.) are needed to show the effect of heat on the physical properties of those steels. New uses would probably be suggested by the results of such a series of tests.

A rapid-steel tool does not finish the piece being cut as nicely as does a simple steel tool, as the rapid steel does not keep a fine edge with a light cut and slow speed of, say, 20 feet per minute. The durability of such a tool taking a light cut is much greater at a higher cutting speed, at which the tool is hotter, showing that the strength or the toughness of the steel or both are augmented by the higher temperature. Unhardened simple steels with 0.6 to 0.7 per cent carbon get stronger but less ductile with a rise of temperature up to about 300° C. (572° F.). If, as the temperature rises, high-speed steels get stronger without loss of ductility but perhaps with an in-

[a] Boynton, H. C., Hardness of the constituents of iron and steel: Jour. Iron and Steel Inst., 1906, p. 287.
[b] Taylor, F. W., On the art of cutting metals: Trans. Am. Mech. Eng., vol. 28, 1906, pp. 31-350.
[c] Herbert, E. G., The testing of files and tool steels: Trans. Manchester Assn., Eng., 1908-1909, pp. 302-317.
[d] Edwards, E. T., Composition of high-speed tool steel: Iron Age, vol. 89, April, 1912, pp. 957-960.

crease, within limits of course, a physical reason for their great durability is provided.

In 1910 Herbert[a] announced the discovery that any rapid-steel tool and some simple steel tools may have two rather widely separated cutting speeds at which the tool is more durable than at speeds above, below, or between. Thus out of many cases described, one tool cooled in an air jet had nearly equal maximum durability at two speeds—50 and 90 feet per minute, whereas at 65 feet the durability was less than one-half of that at either of the other speeds. This discovery no doubt accounts for some of the anomalies encountered in tool steels as well as other steels the properties or performances of which are not what would be expected from their composition and other attributes. Thus a tool may be condemned when an increase of its cutting speed would cause it to give satisfactory service and durability.

Rapid steel will do its best cutting when hot. A desirable practice followed in some shops, is to heat a tool to near redness before putting it to work.

MACHINE-TOOL DESIGN.

When Taylor and White first introduced rapid steels it was thought that the higher cutting speeds afforded constituted the sole benefit to be derived from them, and as the higher speeds, although consuming more power about in proportion to the increase in speed, did not increase materially the stresses on the machine tools, it was thought that the latter merely needed to be speeded up in order to get the full benefit from the new steels. But it was soon found that the rapid steels in addition to cutting at higher speeds were capable of taking much heavier cuts, which proportionately increased the stresses on the tools. To take full advantage of the heavier as well as the more rapid cuts, machine tools were generally redesigned to provide the greater strength required, and were supplied with proportionately more power. The resulting economies all over the world have been enormous.

The advantages from the use of rapid steels as compared with the use of simple tool steels are in the lessened costs of the ordinary operations of finishing iron and steel because of:

1. More rapid cutting speed.
2. Heavier chips cut, hence larger cuts and feeds.
3. Saving of power per unit of metal cut off.
4. Lower cost of plant for a given output.
5. Lower general and overhead charges connected with manufacturing iron and steel products.

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[a] Herbert, E. G., The cutting properties of tool steel: Jour. Iron and Steel Inst., 1910, pt. 1, p. 216.

PATENTS ON HIGH-SPEED STEELS.

Since the original Taylor and White patents for treatment of high-speed steels were issued in 1901, others have been granted for almost every possible combination of elements which were in any way thought to be useful or valuable constituents of tool steel. Chromium and tungsten were generally included, though not always. Nevertheless most makers now aim at substantially the same foundation composition, with varying amounts of vanadium and sometimes with cobalt.

MISCELLANEOUS USES OF HIGH-SPEED STEELS.

An important use for high-speed steel is in the exhaust valves for automobile engines, where it has given excellent results. These valves operate sometimes at a red heat and seemingly the property of red-hardness that the steel possesses enables it to give good service in these valves.

High-speed steel is being used also in the manufacture of extruded brass to form the die through which the extruded metal is forced. The temperature of the brass is high, near its fusion point, and seemingly the red-hardness of the steel enables the steel to perform this service satisfactorily.

A good file or a good cold chisel may be made of rapid steel, but they are not good enough to justify their cost as compared with those made of simple steels.

BIBLIOGRAPHY ON HIGH-SPEED TOOL STEEL.

ENGINEERING. Rapid tool steels. Vol. 76, Aug. 21, 1903, pp. 255–256.

GLEDHILL, J. M. The development and use of high-speed tool steel. Jour. Iron and Steel Inst., 1904, pt. 2, pp. 127–181.

MARKHAM, E. A. The use of high-speed steels. Am. Machinist, vol. 27, pt. 1, Apr. 7, 1904, pp. 443–444.

NICOLSON, J. T. Experiments with a lathe-tool dynamometer. Proc. Inst. Mech. Eng., 1904, pts. 3–4, pp. 883–935.

PENDLEBURY, C. Notes on tests of rapid-cutting steel tools. Engineer (London), vol. 97, Apr. 1, 1904, pp. 331–332.

CARPENTER, H. C. H. The types of structure and the critical ranges on heating and cooling of high-speed tool steels under varying thermal treatment. Jour. Iron and Steel Inst., pt. 1, 1905, pp. 433–473.

NEWBOLD, S. The Taylor-Newbold saw. Foundry, vol. 27, November, 1905, pp. 118–121.

CARPENTER, H. C. H. Tempering and cutting tests of high-speed steels. Jour. Iron and Steel Inst., pt. 3, 1906, pp. 377–396.

CLARAGE, E. T. The manufacture of tool steel. Am. Machinist, vol. 29, pt. 2, Nov. 1, 1906, pp. 573–576. An address delivered before the Northwest Railway Club.

TAYLOR, F. W. On the art of cutting metals. Trans. Am. Soc. Mech. Eng., vol. 28, 1906, pp. 31–350.

AUCHY, GEORGE. The theory of high-speed tool steel. Iron Age, vol. 80, Dec. 26-1907, pp. 1818–1822.

CARPENTER, H. C. H. An analysis of the evolution of modern tool steel. Engineer, ing, vol. 83, 1907, pp. 569, 633.

EDWARDS, C. A. Function of chromium and tungsten in high-speed tool steel. Jour. Iron and Steel Inst., pt. 2, 1908, pp. 104–132.

VALENTINE, A. L. Making and using of high-speed steel tools. Am. Machinist, vol. 31, pt. 2, July 2, 1908, pp. 6–9.

CARPENTER, H. C. H. Possible methods of improving modern high-speed turning tools. Trans. Manchester Assn. Eng., 1908–1909, pp. 81–120.

HERBERT, E. G. The testing of files and tool steel. Trans. Manchester Assn. Eng., 1908–1909, pp. 317–402.

ENGINEER (London). High-speed tool steels. Vol. 107, 1909, pp. 289, 347. Describes results of tests at Sheffield works.

BECKER, O. M. High-speed steel. 1910. 360 pp.

BERG, C. P. Heat treatment of high-speed tools. Jour. West. Soc. Eng., vol. 15, 1910, pp. 738–764.

BRACKENBURY, H. I. High-speed tools and machines to fit them. Proc. Inst. Mech. Eng., 1910, pts. 3 and 4, pp. 929–955, 986–1026.

SMITH, W. G. High-speed steel and its heat treatment. Mech. Eng. (Manchester), vol. 25, May 6, 1910, pp. 537–540.

BREARLEY, HARRY. The heat treatment of tool steel. London, 1911.

GLEDHILL, J. M. The practical use of high-speed tool steel. Mech. Eng. (Manchester) vol. 27, June 23, 1911, pp. 762–766.

SULLIVAN, W. B. Tool steel. Proc. New York Railroad Club, vol. 22, 1911, pp. 2595–2633.

EDWARDS, E. T. Composition of high-speed tool steel. Iron Age, vol. 89, April 18, 1912, pp. 957–960.

HAMMOND, E. K. The manufacture of tool steel. Iron Age, vol. 90, Oct. 3, 1912, pp. 766–771.

HERBERT, E. G. The influence of heat on hardened tool steels, with special reference to the heat generated in cutting operations. Jour. Iron and Steel Inst., 1912, pt. 1, pp. 358–377.

KENNEY, L. H. Tool steel for the United States Navy. Trans. Soc. Naval Arch. and Marine Eng., vol. 20, 1912, pp. 345–574.

MACHINERY. Steels for taps, drills, and milling cutters. Vol. 19, November, 1912, pp. 181–182.

SULLIVAN, W. B. A study of the proper hardening and classification of tool steels. Proc. Railway Club of Pittsburgh, vol. 11, April 26, 1912, pp. 155–185. Gives results of drilling tests.

BIGGER, C. M. Tool steel from a salesman's point of view. Iron Age, vol. 91, March 20, 1913, pp. 706–708.

RIPPER, WILLIAM, and BURLEY, G. W. Cutting power of lathe turning tools. Proc. Inst. Mech. Eng., 1913, pts. 3 and 4, pp. 1067–1210.

SCHLESINGIER, G. Die Fortschritte deutscher Stahlwerke bei der Herstellung hochlegierter Schnellarbeitsstähle. Stahl und Eisen, Jahrg. 33, June 5, 1913, pp. 929–939.

CHROMIUM-VANADIUM STEELS.

Chromium-vanadium steels, usually called in the trade chrome-vanadium steels, are the latest development in structural alloy steels that have gained an extensive market. In 1913 about 90,000 tons of ingots is thought to have been made, of which about 75,000 tons

made in the open-hearth furnace, the chromium and vanadium alloys being added shortly before casting.

The hot working of chrome-vanadium steels presents no especial difficulties. The total amount of alloying elements is not large in the commercial grades, and the steel acts in the press and rolls much like simple steels with somewhat higher carbon contents.

Chrome-vanadium steels are in their physical properties much like chrome-nickel steels, but they have a greater contraction of area for a given elastic limit than the latter.

This higher contraction of area in the pulling test seems in some way to be associated with machinability, as chrome-vanadium steel with an elastic limit of 150,000 pounds per square inch may be machined rapidly, whereas a chrome-nickel steel having such an elastic limit would quickly dull the cutting tool if cut at the same speed.

The greater part of the chrome-vanadium steels made goes into automobiles. They are preferred by some because of their greater freedom from surface imperfections, notably seams, which steels containing nickel are prone to have if the ingots are at all unsound. Vanadium is a deoxidizer, whereas nickel is not, so that vanadium, when present, favors quality, and the smaller proportion required enables it to compete with nickel even though its cost is five or six times as great.

Chrome-vanadium steels are nearly always used in the heat-treated condition, but there are exceptions even in automobiles, as some frames, forgings, and shafts are made of the steel in its natural state. When heat-treated these steels are both hardened and drawn at slightly higher temperatures than are used with nickel-chromium steels to get similar properties. These temperatures are given in the table of hea[illegible]ated chrome-vanadium steels.

S[illegible]me-vanadium steel is said to be used in armor plate of med[illegible]kness (4 inches), which is not face-hardened but has high[illegible]ies [illegible]parted by heat treatment. Some such steel is use[illegible]gings and structural parts of machines.

[illegible]*operties of chrome-vanadium steels in natural state.*

[illegible]n.			Tensile properties.				
[illegible]	V.	Cr.	Tensile strength.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	Ball hardness.
	P. ct.	*P. ct.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	
[illegible]	0.31	1.36	98,000	75,750	68.5	28.1	175
[illegible]	.14	1.17	82,250	52,500	71.0	34.0	160
[illegible]	.20	.74	60,500	42,900	75.0	43.0	133
[illegible]	.18	.90	.....	45,000	69.0	35.0	[a] 155

[a] Annealed.

Composition and properties of chrome-vanadium steels in heat-treated state.

Sample No.	Composition.							Tensile properties.					Treatment.[a]
	C.	Mn.	Si	S.	P.	Cr.	V.	Tensile strength.	Elastic limit.	Contraction of area.	Elongation in 2 inches.	Ball hardness.	
	P.ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*Pounds.*	*Pounds.*	*P.ct.*	*P.ct.*		
1	0.30	0.65	0.10	0.04	0.04	0.90	0.18	.....	101,000	64	20	255	899° W; 704° A.
2	.30	.65	.10	.04	.04	.90	.18	.....	180,400	43	10	430	899° W; 454° A.
3	.30	.65	.10	.04	.04	.90	.18	.....	200,000	52	10	429	899° W; 315° A.
4	.28	.45	.26	.02	.01	1.00	.18	96,500	79,000	75	34	187	899° O; 676° A.
5	.40	.75	.26	.01	.01	1.00	.17	148,000	120,000	53	20	270	926° O; 676° A.
6	.40	.75	.26	.01	.01	1.00	.17	221,000	200,000	48	11	435	926° O; 426° A.
7	.57	.37	.20	.02	.01	.69	.22	188,200	177,500	57	14	330	—; 426° A.
8	1.06	.36	.22	.02	.02	.95	.11	135,550	126,750	49	21	248	—; 648° A.
9	.41	.49	.12	.03	.03	1.09	.11	86,900	77,250	70	33	152	—; 754° A.
10	.25	.50	.10	.03	.02	.95	.75	131,700	113,100	56	18	.....	.....

[a] The first temperature given for each sample is that at which the steel was quenched, and the second the drawing temperature; W, O, and A represent water, oil, and air, the three cooling media used. Samples 8, 9, and 10 were hardened before being drawn at the temperatures given.

EXAMPLE OF SATISFACTORY USE OF CHROME-VANADIUM STEEL.

A hydroelectric plant had shafts 6½ inches in diameter, which transmitted 3,000 kw. each at 480 revolutions per minute, and all broke in service. The shafts were made of untreated nickel steel having an elastic limit of about 40,000 pounds per square inch. To make stronger shafts by increasing their size not being practicable, other shafts were made under the specification that the elastic limit of the steel should be at least 105,000 pounds per square inch, its contraction of area 40 per cent, and its ball hardness uniform within 5 per cent. Shafts to meet such qualifications were made of chromium-vanadium steel containing 0.33 per cent C, 0.54 per cent Mn, 0.022 per cent P, 0.030 per cent S, 0.89 per cent Cr, and 0.24 per cent V. The ingot, which was 30 by 25 inches in section, was rolled to an 18 by 18 inch bloom or billet, and the shafts were forged therefrom. The shafts were heat-treated, and a test from one of them, about the average of all those made, pulled at Watertown Arsenal on a 2-inch by 0.505 diameter section, gave results as follows:

Results of tests of heat-treated chrome-vanadium steel shaft.

Elastic limit.	Tensile strength.	Elongation.	Contraction.	Ball hardness.
Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	
105,260	127,310	15	46.2	278
.....	.....	.....	.....	283
.....	.....	.....	.....	278

These shafts met the specifications and proved satisfactory in service.

BIBLIOGRAPHY ON CHROMIUM-VANADIUM STEEL.

SANKEY, H. R., and SMITH, J. K. Heat-treatment experiments with chrome-vanadium steel. Proc. Inst. Mech. Eng., 1904, pts. 3 and 4, pp. 1235–1317.

LAKE, E. F. Some properties of vanadium steel. Am. Machinist, vol. 30, pt. 1, May 2, 1907, pp. 632–634. Gives results of tests of chrome-vanadium steel.

GIBBS, W. E. Vanadium steel. Cassier's Mag., vol. 38, June, 1910, pp. 174–181.

SMITH, J. K., and TURNER, W. L. Vanadium and metallurgy. Iron and Coal Trades Rev., vol. 81, 1910, pp. 389, 463, 585, 663.

IRON TRADE REVIEW. Chrome-vanadium tire tests. Vol. 51, Dec. 26, 1912, pp. 1217–1218.

MITCHELL, A. F. Heat treatment of chrome-vanadium steel. Proc. Railway Club of Pittsburgh, vol. 12, Dec. 19, 1912, pp. 38–66.

IRON AGE. Chrome-vanadium rolled-steel wheels. Vol. 92, Nov. 13, 1913, p. 1106.

RECOVERING ALLOYED ELEMENTS.

As the alloying elements of alloy steels are all more valuable than iron, some of them very much so, makers of alloy steels wish, of course, to save such elements in their alloy-steel scrap, if practicable without too great cost. The makers can save tungsten, copper, nickel, and cobalt, each of which has an affinity for oxygen and a heat of combustion with oxygen less than the similar properties of iron; however, the makers can not at present save the manganese, silicon, vanadium, titanium, calcium, magnesium, and chromium, each of which has an affinity for oxygen and a heat of combustion greater than the similar properties of iron. Plans have been proposed for saving some of them. Saving a part of these oxidizable elements in reworking the scrap is in some instances of no benefit, because in replacing the wasted part by the addition of a fresh quantity of the ferro-alloy saturated with carbon there will be too much carbon in the finished steel. This is particularly true of manganese in manganese-steel scrap. The carbon in the alloy-steel scrap is protected from oxidation by the alloying element while the latter is being oxidized. With low-carbon alloy available the case is different, as the content of carbon in the steel may then be controlled.

CERIUM PYROPHORIC ALLOY.

The pyrophoric metal used on cigar lighters and for igniters in miner's lamps might be considered as an alloy steel, as it consists substantially of 30 per cent of iron with 70 per cent of cerium. It was patented by Welsbach, whose name is identified with the Welsbach light. The striker is of the grade of hardened file steel with about 1.50 per cent carbon. The detached particles of the cerium-iron alloy take fire in the air, ignition being quickened no doubt by the heat generated in the impact of the striker.

CONCLUSION.

Further advance in the development of new alloy steels, as well as many new applications of those alloy steels already established, are to be expected. Trials are continually being made of new alloys of promise, some of which will doubtless win place in the list of useful alloy steels. Hadfield's iron alloy containing 5 per cent manganese and 15 per cent nickel, although not at present of use, may become so in the future, as its properties are rather remarkable.

As some of the alloys in steel, as well as any heat treatment it may have received, affect the carbon contained so that its effect in the color determination is changed, the regular practice in some steel-works laboratories is to make all carbon determinations gravimetrically by direct combustion of the whole sample with oxygen. This procedure avoids the uncertainties and errors of the color determination in analyzing heat-treated alloy steels.

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PUBLICATIONS ON MINERAL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

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BULLETIN 85. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913, by A. C. Fieldner, H. I. Smith, A. H. Fay, and Samuel Sanford. 1914. 444 pp., 2 figs.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp., 1 fig.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells, as practiced in California, by Ralph Arnold and V. R. Garfias. 1912. 12 pp., 1 fig.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas, and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 24 pp., 2 figs.

TECHNICAL PAPER 81. The vapor pressure of arsenic trioxide, by H. V. Welch and L. H. Duschak. 1915. 22 pp., 2 figs.

TECHNICAL PAPER 88. The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915. 29 pp., 1 pl., 4 figs.

TECHNICAL PAPER 90. Metallurgical treatment of the low-grade and complex ores of Utah, a preliminary report, by D. A. Lyon, R. H. Bradford, S. S. Arentz, O. C. Ralston, and C. L. Larson. 1915. 40 pp.

TECHNICAL PAPER 110. Monazite, thorium, and mesothorium, by K. L. Kithil. 1915. 32 pp.

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